Integrated Education for the *Real World*
5th International STEM in Education Conference

**Post-Conference Proceedings**

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Keynotes

Disruption and Learning Innovation across STEM

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BIOGRAPHY

Lyn English is Professor of STEM in Education at the Faculty of Education, QUT. Her areas of research include mathematics education, engineering education, integrated STEM learning, mathematical modelling, problem solving and posing, statistics education, and mathematical reasoning and development. Professor English’s research has been supported for over two decades by many grants from the Australian Research Council. She was awarded the Mathematics Education Research Group of Australasia Career Research Medal, 2012, and the Vice Chancellor’s Award for Excellence in Research in 2015. She is a Senior Research Scientist (Adjunct) of the Kaput Center for Research and Innovation in STEM Education at the University of Massachusetts Dartmouth. Professor English is a Fellow of The Academy of the Social Sciences in Australia, and is founding editor (1997) of the international journal, Mathematical Thinking and Learning (Taylor & Francis).

ABSTRACT

Disruption is rapidly becoming the norm in almost all spheres of life including business, industry, politics, culture, and the media. These upheavals stimulate disruptive thinking, where perspectives on commonly accepted (and often inefficient) solutions to problems are rejected for more innovative approaches and products. STEM education, in particular STEM integration, provides an ideal vehicle for developing the foundations of disruptive thinking, where learning innovation is fostered. For this presentation, learning innovation entails the processes of generating new knowledge and ideas that can be applied to solving a novel problem. Such learning is proposed as central to dealing effectively with disruption and requires the development of both discipline content knowledge and the adaptation and application of this knowledge to the solution of new problems. In illustrating ways in which learning innovation might be achieved in STEM integration, I draw on examples of modelling with design.

Keywords: Disruption, disruptive thinking, STEM integration, learning innovation, modelling, design processes

Promoting STEM education across the school years is a core goal of governments and organisations worldwide (e.g., Canada 2067, 2017; Education Council, 2015; EU STEM Coalition, n.d.; Lucas, Claxton, & Hanson, 2014; Marginson, Tytler, Freeman, & Roberts, 2013). Many business and industry organisations repeatedly emphasise the need to address
the shortfalls in STEM education, where STEM related skills and knowledge are increasingly needed across a broader range of fields. As noted in a recent PwC report (2016), “building a STEM capable workforce begins with education and the primary years are crucial in establishing foundational skills, knowledge, and curiosity about STEM concepts” (p. 11). Common global concerns for how to improve STEM education are compounded by the longstanding debates on the nature of STEM education, whether the disciplines should be integrated and approaches to doing so, and whether students are being adequately prepared for our ever-changing STEM world. With terms loosely defined and directions for action seemingly in disarray (e.g., US Dept. of Education, 2016), our role as STEM educators is made all the more challenging.

In this paper I argue that STEM education and especially integrated STEM is an ideal vehicle for preparing students for dealing effectively with the increasing disruption in our local and global spheres. I first give consideration to the notions of disruption and disruptive thinking, and why education must adapt to a disruptive world. I then review approaches to STEM integration and how integrated STEM challenges can facilitate learning innovation in the face of disruption. In advancing learning innovation as a core feature of STEM integration, I propose that modelling with design can foster such learning. The plenary presentation will include examples to illustrate the core ideas presented.

DISRUPTION AND DISRUPTIVE THINKING

Disruption is the new norm across business, politics and culture … you can either lead change or be a victim of it (Switzer, Australian Financial Review, 26th December 2017, p. 20).

Across business and industry, a myriad of articles and media reports are warning of the disruption threatening the survival of companies, with only “the paranoid” surviving (Crittenden, Crittenden, & Crittenden, 2017, p. 14; Grove, 1996). The self-driving car industry is a prime example of technological disruption that car manufacturers are facing (Rusko et al., 2018). However, as Rusko et al. (2018) indicated, driverless cars are still emerging because the key technology and production mechanisms are yet to be fully realised. Driverless cars need 3-D maps, which present major challenges currently being targeted (e.g., by MIT researchers). Specialists from across the STEM spectrum are needed in bringing this innovation to fruition. Likewise, the development of biofuels for the airline industry, facial recognition in place of credit card PIN numbers, and the upsurge in quantum computing are disrupting the world as we know it; without the STEM fields, these innovations would not realise their potential.

Education can ill afford to ignore the disruption arising from advances in the STEM fields. Unlike business and industry, where disruption creates a “force-to-innovate” approach (Crittenden, 2017, p. 14), much of school education seems oblivious to preparing students for these disruptive forces or at least are restricted in doing so by set curricula. Interestingly, the need to change this situation is repeatedly highlighted by government reports, as evident in the recent 2017 report from Innovation and Science Australia (Australian Government, 2017). The first of the report’s five imperatives is the improvement of the teaching of STEM and 21st century skills. As the chairman of Innovation and Science Australia warned, “Unless we change our education system we won’t be able to equip our kids with the skills they will need for a rapidly changing economy (The Australian, 30th January 2018, p. 20).

How then, should education, and in particular STEM education, respond to increasing global disruptions and nurture the innovation skills required? Insights from industry and
business can provide catalysts for change. Numerous reports highlight not only the importance of STEM competencies, including the increasing need for digital literacy, but also 21st century skills as industries deal with changes brought about by disruptive forces (e.g., Canada 2067, 2017; Commonwealth of Australia, 2017). A common set of employee capabilities cited by industry leaders includes developing agility, innovative insights, diversity of thought, flexible strategies, creative ideas and solutions, adaptable behaviours, and courageous dispositions (e.g., Australian Financial Review, 27th December 2017, 22nd January 2018; The Australian, 2018). These capabilities are foundational to STEM education. Developing such capabilities in a curriculum that features opportunities for disruptive and innovative thinking would appear paramount. Problems that challenge students’ existing ideas and approaches, invoking solutions that go against conventional or expected responses (Sternberg, 2017), can foster the learning innovation needed for today’s world. Yet despite STEM education being in a prime position for preparing students for disruption, we are not realising the potential of these disciplines. STEM education needs to be at the forefront of disruptive and innovative thinking, just as companies need to continually innovate to survive or avoid a take-over. Companies cannot stand still in today’s disruptive climate; nor can countries; nor can education. STEM integration in particular, as in the real-world, offers rich opportunities for stimulating change and fostering learning innovation.

STEM AND STEM INTEGRATION

Returning to the case of driverless cars, Rusko et al. (2018) highlight technological disruption as a stimulus for the “coopetition” (p. 35) between companies that are in competition. The cooperation of competitive networks is an important strategy for developing disruptive technologies in meeting market needs. For example, Google has invested in self-driving cars where sensors and software sense objects including pedestrians. The major car companies such as Toyota are cooperating with these technology firms and with ride-hailing service companies such as Uber Technologies Inc. to create a network of on-demand, driverless vehicles in the US. Toyota has the resources and the potential to develop and manufacture self-driving cars, while Uber has expertise in ride-hailing services, which is important for the development of these cars. Both companies can enter this new market and develop a competitive advantage that otherwise would be difficult to snare. These cases provide just a few examples of how STEM integration in the real-world is promoting innovations arising from disruption. Likewise, STEM education in schools needs to take advantage of the natural linkages across the disciplines and the rich learning such connections, sometimes unanticipated, can offer. Engineering, in particular, provides a core link across the disciplines yet it is largely ignored in STEM programs (e.g., English, 2017; Moore & Smith, 2014).

Numerous interpretations of STEM education and integrated STEM abound. It is beyond the scope of this paper to address the myriad viewpoints, which vary in scope and specificity (e.g., Bryan, Moore, Johnson, & Roehrig, 2015; Bybee, 2013; Vasquez, Schneider, & Comer, 2013). Nevertheless, it is worth mentioning the perspectives of Vasquez et al. (2013), where different forms of boundary crossing are displayed along a continuum of increasing levels of interconnection and interdependence among the disciplines. These crossings range from simple disciplinary approaches, where concepts and skills are learned separately in each discipline, to multidisciplinary forms involving concepts and skills in each discipline being learned separately but within a common theme, and finally, transdisciplinary approaches where knowledge and skills learned from two or more disciplines are applied to real-world problems and projects, thus shaping the total learning experience. Shaughnessy’s (2013) definition of STEM education incorporates integration and is the preferred perspective
in this paper, namely, “STEM education refers to solving problems that draw on concepts and procedures from mathematics and science while incorporating the team work and design methodology of engineering and using appropriate technology” (p. 324).

Although integrated approaches can enhance students’ interest in STEM and improve their problem-solving and analytical skills (e.g., Masters, 2016; Moore & Smith, 2014), such approaches remain controversial. A major concern lies in maintaining the integrity of the respective disciplines (e.g., English, 2015; Honey, Pearson, & Schweingruber, 2014; Shaughnessy, 2013). Yet, increasingly STEM education is being promoted as integrated, as recently noted in an Australian Council for Educational Research report addressing Challenges in STEM Learning in Australian Schools (Timms, Moyle, Weldon, & Mitchell, 2018).

LEARNING INNOVATION

STEM integration provides many opportunities to foster what I term, learning innovation. Such learning entails the processes of student generation of new knowledge and ideas that can be adapted and applied to solving a novel problem (English & King, 2018). Learning innovation involves the development of both discipline content knowledge and the adaptation and application of this knowledge to the solution of new problems. Developing such learning should be a primary goal of education that prepares students for present and future disruption. A long-standing, challenging goal in education is developing students’ robust understandings that they can apply to decision making and problem solving in other situations both within and beyond school (e.g., Hohensee, 2014; Lobato, 2006; McKenna, 2014).

Innovative learners (and educators) have the potential to become adaptive problem solvers, who can more readily entertain disruption, can tackle new and unexpected situations, and can see the novel in the ordinary. Drawing on McKenna’s (2014) notion of “adaptive expertise” (p. 232), I argue that becoming an adaptive problem solver involves a balance between developing STEM competencies (discipline knowledge) and developing learning innovation (knowledge generation), as illustrated in Figure 1 (adapted from McKenna, 2014; and Schwartz, Bransford, & Sears, 2005). Figure 1 displays this balance between developing learning innovation and STEM discipline knowledge, with an “optimal adaptability corridor” displayed. This corridor indicates that both learning innovation and STEM competencies are maximally fostered. In other words, the focus is on “what might be” rather than on “what is” in advancing STEM education (Gadanidis, Clements, & Yiu, 2018, p. 35). One approach to developing learning innovation and adaptive expertise is through modelling with design (English & King, 2018).

![Figure 1. Learning innovation: becoming an adaptive problem solver (English & King, 2018)](image)
MODELLING WITH DESIGN ACROSS STEM

Modelling with design has the potential to promote learning innovation and adaptive expertise since the very nature of design requires recognising how prior knowledge might be applied under new and unexpected circumstances (McKenna, 2014). The notion of design adopts different forms in different disciplines and contexts (e.g., Crismond & Adams, 2012; Wright & Wrigley, 2017), and is increasingly being used across the STEM disciplines and beyond (as noted by Kelley & Sung, 2017). Likewise, the term, modelling, has been applied variously in mathematics education (e.g., Anhalt, Staats, & Cortez, 2018; English, Arleback, & Mousoulides, 2016). Frequently, solutions to design problems and mathematical modelling problems do not yet exist (McKenna, 2007) or, at least, are not within the realm of the problem solver’s “toolkit” of solutions and experiences. Both problem types are typically ambiguous, with multiple approaches and multiple solutions possible, some more effective than others. The focus is on the interpretation and reinterpretation of problematic information and on the iterative development of disciplinary knowledge as models are formed, tested, and refined in response to certain specifications. Modelling with design is thus defined as an iterative activity (creating-testing-refining) where shared processes of mathematical modelling and engineering design, together with science competencies, are applied in solving complex, system-based problems (English & King, 2018).

As the frequently forgotten component of STEM education, at least in primary and secondary schools, engineering provides a powerful disciplinary link in integrated programs (Bryan et al., 2015; DiFrancesca, Lee, & McIntyre, 2014; English, 2016; King & English, 2016). Yet engineering is a featured content component of both the Australian Curriculum: Design and Technologies and the US Next Generation Science Standards (Next Generation Science Standards [NGSS], n.d.). Engineering design is typically described as iterative thinking in dealing with a complex problem— that is, scoping the problem, creating solution ideas, designing and generating models, testing, redesigning and revising/refining—as well as working in teams and communicating current ways of thinking (English & King, 2015; Moore & Smith, 2014). The focus however, is not just on process iteration towards a solution model but also iteration toward discipline understanding and learning generation (cf., English, King, & Smeed, 2017; McKenna, 2014).

The plenary will include classroom examples of how learning innovation can be fostered in the primary and middle school. Specifically, consideration will be given to STEM-integrated experiences where students are encouraged to move beyond basic problem solving towards situations that call for innovative and adaptive approaches where new knowledge is generated and applied.

CONCLUDING POINTS

Disruption arising from innovations in the STEM fields will continue to confront us all—at an alarming pace. It is imperative that education in our schools and beyond takes heed of these disruptive forces. As reports from businesses and governments emphasise, education must better prepare students for a rapidly changing and disruptive world. Our students are “digital natives” yet this doesn’t mean they are equipped with the STEM skills required for embracing the increasing disruption that will impact their lives. This paper has argued that STEM integration has the potential to develop the foundations of disruptive thinking, where learning innovation is fostered. Modelling with design has been advanced as providing a vehicle for learning innovation because it provides a corridor for optimal knowledge generation and adaptation to new problems.
REFERENCES


The Winning 2030 CV
Dr Alan Finkel
Australia’s Chief Scientist,
Office of the Chief Scientist

BIOGRAPHY
Dr Finkel commenced as Australia’s Chief Scientist on 25 January 2016. He is Australia’s eighth Chief Scientist. Prior to becoming Chief Scientist, he was the eighth Chancellor of Monash University and the eighth President of the Australian Academy of Technology and Engineering (ATSE).

Since commencing as Chief Scientist, Dr Finkel has led the Review into the National Electricity Market (“Finkel Review”) and the 2016 National Research Infrastructure Roadmap. He currently leads the STEM Industry Partnership Forum for the COAG Education Council and serves as the Deputy Chair of Innovation and Science Australia.

Dr Finkel has an extensive science background as an entrepreneur, engineer, neuroscientist and educator. He was awarded his PhD in electrical engineering from Monash University and worked as a postdoctoral research fellow in neuroscience at the Australian National University.

ABSTRACT
What awaits our students in the workplaces of 2030? Models and opinions abound, but physicist Niel Bohr’s aphorism remains all too true: prediction is very difficult, especially if it’s about the future. So should we position our students to be generalists, with a focus on soft skills? Double-down on disciplinary content knowledge and skills instead? Or prepare a generation for a world where humans are no longer required to work?

Australia’s Chief Scientist Dr Finkel reaffirms the centrality of STEM education to the human future we want to create, with a plea for the strengths of the disciplines to be retained.
BIOGRAPHY

Felicity has been curious her whole life about how things worked and passionate about creating things for people, so becoming a Civil Engineer and social entrepreneur was almost logical.

After realising the lack of diversity in engineering, which is largely due to the misperceptions of the industry, Felicity co-founded not-for-profit Power of Engineering. The organisation has now reached over 8,000 students across Australia through one day events and partnerships with industry and universities. 75% of students who were a ‘no’ to engineering before the day change their mind to a ‘yes’ after the event.

Wanting to make a bigger, longer term impact, Felicity co-founded social enterprise Machinam which engages and motivates students in maths. Machinam’s digital maths resource, In Real Life for year 9 and 10, connects what students are learning in maths class to the real world and authentically how they would use maths.

This work, along with her professional career, saw Felicity named as one of the Financial Review BOSS Magazine’s Young Executives of the Year in 2016 and named as one of Australia’s ‘100 Women of Influence’ at just 26 years old.

Felicity’s ten year corporate career includes working as a Senior Project Manager at innovative engineering consultancy Arup, Management Consultant at fortune 500 company AECOM and delivering a $45 million dollar transport infrastructure project portfolio for local communities with Brisbane City Council

ABSTRACT

How do we create, plan and invent a future that doesn’t exist yet? How will we solve the challenges of water or food shortages, energy crises and invent products to make our world a better place? To build the future we need all citizens to have critical and creative thinking skills. What better way to get these skills, but through STEM education, but how can we engage students in STEM?

To engage students we must

- bring the real world into the classroom
- understand and communicate the ‘why’ of what we do in STEM not just the ‘how’
- engage a diverse range of learners, particularly girls into STEM
- create adaptable, creative and innovative STEM professionals
Thriving in the digital age: The future of learning

Professor Marek Kowalkiewicz
Professor and PwC Chair in Digital Economy
Queensland University of Technology, Australia

BIOGRAPHY

Dr Professor Marek Kowalkiewicz is an academic and industry leader with extensive experience in conducting academically sound research, co-innovating with industry and university partners, and delivering innovative products to the market. Currently, as Professor and PwC Chair in Digital Economy, as well as Leader of the Embracing Digital Age research theme, he leads Queensland University of Technology’s research agenda to inform and influence a robust digital economy in Australia and the region. He joined QUT from Silicon Valley, where he led innovation teams of one of the largest enterprise software vendors in the world. Before Silicon Valley, Marek worked in Singapore, Australia and China. Marek manages a contemporary research portfolio and converts industry driven opportunities into research outcomes of global relevance. He is an invited government expert, university lecturer and project lead, as well as an inventor and author.

Marek is recognised as a top quality manager and excellent public speaker, and has an interest in working with stakeholders in developing innovative ideas, ground-breaking business applications and high-impact new technologies. For more info about Marek and his work:

- http://studentdesignjam.com
- http://pwcdisruptiveinnovation.com

ABSTRACT

The digital economy provides organisations and leaders with the opportunity to reimagine how they do business, innovate customer-centric solutions to complex problems, and to create new value. It also requires us to reimagine the future lives of students in the Digital Age.

This interactive, high-energy presentation delivered by Prof Marek Kowalkiewicz, one of Australia’s leading digital transformation experts from QUT will introduce you to the innovation lenses that propagate an opportunity mindset. Gain an understanding of the thinking patterns and practical skills required to proactively identify and capitalise opportunities in the changing industry, create a culture and start a language of innovation in your organisation, and learn how to stimulate creativity to ideate and prototype new ideas.

In his keynote, Marek will also talk about skills needed to thrive in the digital future. Not only what they might be, but more importantly: how to stay future ready and maintain a set of relevant skills.
STEM for Space Junkies

Professor Fred Watson
Australia’s Astronomer-at-Large
Department of Industry, Innovation and Science, Australia

BIOGRAPHY

Fred Watson is the former Astronomer-in-Charge of the Australian Astronomical Observatory. He is now Astronomer-at-Large in the Commonwealth Department of Industry, Innovation and Science, and holds adjunct professorial positions at six Australian universities.

Fred is best known for his radio and TV broadcasts, talks, and other outreach programs, which earned him the 2006 Australian Government Eureka Prize for Promoting Understanding of Science.

He has also written a number of award-winning books, and was made a Member of the Order of Australia in 2010. Fred has an asteroid named after him (5691 Fredwatson), but says that if it hits Earth, it won’t be his fault.

ABSTRACT

We know from repeated surveys that few topics inspire students more than astronomy and space science. These subjects embrace all aspects of STEM, from heavy engineering to relativistic modelling. Yet most teachers at high-school level address them with trepidation, perhaps because they feel they lack the required specialist knowledge.

In reality, the basics of astronomy and space science are more easily understood than those of almost any other STEM-dependent subject. This talk will make the case for an enhanced cosmic component in integrated STEM education for the real world.
PROJECT-BASED LEARNING (PBL) IN PRACTISE: 
ACTIVE TEACHERS’ VIEWS OF ITS’ ADVANTAGES AND CHALLENGES

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ABSTRACT

Teachers’ ability to execute project-based learning (PBL) in practice determines the effectiveness of such learning. Teachers’ implementation of PBL has been shown to greatly affect students’ content understanding and development of skills. (Han, Yalvac, Capraro & Capraro, 2015; Kokotsaki, Menzies & Wiggins, 2016) The purpose of this qualitative study is to understand the views of active teachers on the advantages and challenges of PBL and use these perspectives in order to better promote its’ implementation in teacher education programs and in general teaching practice. Data was collected using an e-survey with some open questions in the context of teachers’ reports of the PBL in an international StarT programme. The data was analysed by a data-driven content analysis (k was from 0.62 to 0.67). 99 active teachers from early childhood to secondary level participated voluntarily on this study. The teachers found PBL very useful to use in their instruction such that it promotes (i) students’ or teachers’ learning and motivation, (ii) collaboration and a sense of community at school level, (iii) student-centered learning, and (iv) brings versatility for their instruction. However, the most challenging aspects of PBL use in practice were: (i) project organization (e.g. time management), (ii) technical issues, (iii) resources, (iv) student-related challenges and (v) collaboration. Teachers’ pedagogical content knowledge in PBL could be promoted for better implementation of PBL in practise through collaborative learning in which students, teachers and other participants are learning from each other.

Keywords: Project-based learning, teachers, teacher education, math and science education, STEM, integrated education

1. INTRODUCTION

Project-based learning (PBL) has a lot of potential to enhance 21st century skills and engage students in real-world tasks (e.g. Bell, 2010; Han et al., 2015). There is evidence that PBL is beneficial both by teachers and students (Thomas, 2010). Earlier research shows that teachers’ understanding of the criteria for effective PBL plays an essential role in how teachers implement PBL, thereby also affecting students’ content understanding and developing skills (Han et al., 2015; Kokotsaki et al., 2016). In relations to STEM education, it has been shown that when PBL is implemented and instructed properly by teachers, student
learn more, whereas teachers who ineffectively implement PBL have negative effect on students’ performance (Han et al., 2015). However, little is known about the challenges experienced by teachers in developing and enacting PBL on their own (Thomas, 2010). Therefore, more research is needed in exploring the advantages and the challenges of PBL from the perspective of active teachers in order to better promote the use of PBL in practice.

According to Thomas (2010), research on PBL has not yet had a substantial influence on PBL practice. By many national curricula (e.g., NGSS, 2014; Finnish National Board of Education, 2014) teachers are now urged to implement integrated and inquiry-based approaches, such as PBL. Thus, teachers are left in a position of having to construct a unique instructional model almost completely on their own without guidance, texts, resource materials, or support (Thomas, 2010). The purpose of this study is to understand how teachers implementing PBL perceive the advantages and challenges of PBL. The teachers studied are active, motivated to develop their teaching and voluntarily taking part in an international StarT programme (https://start.luma.fi/en/) that supports implementation of PBL in their instruction.

2. THEORETICAL BACKGROUND

2.1. Definition of PBL

There are a lot of different definitions for project-based learning (PBL). According to Thomas (2010), it is a model that organises learning around projects. It is also defined as an interdisciplinary, student-centered activity with a clearly defined project outcome (Han et al., 2015). PBL is characterised by students’ autonomy, constructive investigations, goal-setting, collaboration, communication and reflection within real-world practices (Kokatsaki et al., 2016).

Blumenfeld et al. (1991) describe PBL as a comprehensive approach to classroom teaching and learning that is designed to engage students in the investigation of real-world problems. There are two essential components of projects: 1) They require a driving question or problem that serves to organize the project activities 2) these activities should result in artifacts that culminate in a final product that addresses the driving question. The driving question designed by students and/or teachers should not be so constrained that the outcomes are predetermined, leaving students with little room to develop their own approaches to answering the question. Students’ freedom to generate artifacts is critical, because it is through this process that students construct their knowledge. Artifacts are concrete and explicit (e.g., a model, report, videotape, or computer program) representations of the students' problem solutions that reflect emergent states of knowledge. This allows others to provide feedback and permits learners to reflect on and extend their emergent knowledge and revise their artifacts. PBL also places students in realistic, contextualised problem-solving environments. In so doing, projects can serve to build bridges between phenomena in the classroom and real-life experiences; the questions and answers that arise in their daily enterprise are given value and are shown to be open to systematic inquiry. (Blumenfeld et al., 1991)

Thus, the distinctive feature of project-based learning is problem orientation, that is, the idea that a problem or question serves to drive learning activities. The second feature of PBL, constructing a concrete artefact, is what distinguishes project-based learning from problem-based learning. Helle, Tynjälä and Olkinuora (2006) add three other features to PBL. The first, learner control of the learning process, which leaves scope for decisions regarding the pacing, sequencing and actual content of learning. The second, the contextualisation of learning is evident in student projects. The value of authentic or simulated learning contexts
has been argued for both cognitive reasons and by the situated learning camp. The third, characteristic of the project method is its potential for using and creating multiple forms of representation. In modern working life, most tasks require the combined use of (interdisciplinary) knowledge in different forms (e.g., abstract, concrete, pictorial, verbal, as formulae etc). (Helle et al., 2006)

2.2. Advantages and challenges of PBL in practise

Learning responsibility, goal setting, independence, and discipline are outcomes of PBL. It promotes social learning as children practice and become proficient with the twenty-first-century skills of communication, negotiation, and collaboration. The element of choice is crucial for students’ success. Differentiation allows students to develop their own interests and pursue deeper learning. The active learning process of PBL takes students’ various learning styles and preferences into account. When we implement PBL, we allow children to discover who they are as learners. It is important for the teacher to confer with students regularly to ensure that students are on track and developing their ideas and skills fully. These skills are critical for future success in both school and life. Research supports PBL as a tool to engage students in real-world tasks. Real-world projects deepen learning for students. (Bell, 2010)

PBL promotes links among subject matter disciplines and presents an expanded, rather than narrow, view of subject matter. Also, projects are adaptable to different types of learners and learning situations. (Blumenfeld et al., 1991)

Some studies of PBL report unintended, beneficial consequences associated with PBL experiences. Among these consequences are enhanced professionalism and collaboration on the part of teachers and increased attendance, self-reliance, and improved attitudes towards learning on the part of students (Thomas, 2010). A common goal for PBL has been to help students acquire deeper content knowledge, skills as well as feelings of commitment and ownership of their learning (Han et al., 2015). This requires active engagement of students’ effort over an extended period of time (Blumenfeld et al., 1991).

Common barriers to implementing PBL effectively include teachers’ resistance to student-driven learning because they often see this as giving up control of the class. According to a case study on a three year in-service teacher training on PBL by Mentzer, Czerniak, and Brooks (2017), teachers valued inquiry-based instruction used in PBL from the onset, but their teaching style preferences changed slowly to inquiry-based over the course of three years of practicing and teacher training. For example, teachers with little practice on PBL are more prone to resist the idea that students should self-determine their own the important concepts of the lesson. Other barriers with the implementation of PBL are teachers confusing inquiry-based instruction with hands-on activities, inability to motivate students to work in collaborative teams, scaffolding instructions, the development of authentic assessments and overcoming student resistance to employing critical thinking. Also time issues, granting students sufficient autonomy and understanding what this entails as well as melding required curriculum with PBL are noted as barriers in research. (Mentzer et al., 2017)

3. METHODOLOGY

3.1. Data collection

The purpose of this study was to understand the views of active teachers on the advantages and challenges of PBL in practice. Data was collected through an e-survey that was distributed to Finnish teachers from early childhood education to upper secondary school
who were participating on international StarT programme (https://start.luma.fi/en/) during the 2016-2017 school year. Teachers are defined as active teachers in this study because they participated on StarT voluntarily. All participants who applied to StarT during January to March 2017 were given some open research questions in the reporting form of StarT programme. Responding to this form was voluntary. Out of 113 Finnish StarT participating teachers, 99 answered the questions. There were teachers from four different school levels: early childhood education (13%), primary school (57%), secondary school (24%) and upper secondary school (6%).

StarT is an international programme organised annually by LUMA Centre Finland and for the first time in the school year 2016-2017. The aim of StarT is to support collaborative, STEM related and interdisciplinary PBL from early childhood education to upper secondary school. Students’ own ideas for the projects can range from everyday phenomena to complex issues in the society - or even out of this world in space. Students and teachers participate in StarT as a team. The projects allow science, mathematics, and/or technology to be incorporated with art, sports, languages, history, social studies, home economics, and many other subjects in a meaningful way. The students learn together and from each other through collaborative team working and carrying out projects related to their own interests and ideas. The projects can be shorter inquiries or long-term explorations, entire school courses or even stretch out through the entire school year. Each learning community shares the StarT projects of the teams and their school with everybody. They all report a short video and a learning diary. The products are published in the website of StarT. The primary purpose of StarT is to allow for participants to learn from others around the world.

3.2. Data Analysis

The analysis was done by data-driven qualitative content analysis (Cohen, Manion, & Morrison, 2013) with phrases and sentences as coding units. The data consist of written answers to following three open-ended questions:

1. What is the experience of the learning community as a participant in StarT?
2. What has been the most useful in StarT project working from your view?
3. What has been the most challenging in StarT project working from your view?

The data was organised for the analysis as a whole set of each teacher answers because the teachers described often experiences included notions of both advantages and challenges of PBL. Then, the data was reduced by coding. There were altogether 96 codes for the advantages and 22 codes for the challenges observed. Two examples of the naming of subcategories:

“We learned a lot more than we originally thought” (the code named “learning in general”)

“Both adults and children have learned a lot about space, planets and stars” and “biology concepts breathing, photosynthesis etc were learned on the fly” (the code named “learning content knowledge”)

The final categorization of the codes was tested by two researchers outside of the study. Cohen's kappa was good, ensuring the reliability of the findings: it was k=0.62 for the codes of advantages and k= 0.67 for the codes of challenges.

4. RESULTS AND DISCUSSION

4.1. The advantages of PBL in practise

The teachers found a lot of advantages of using project-based learning in their teaching, as shown in Table 1. Mostly teachers valued PBL for its possibilities for learning. This could
be in general learning or related to students’ skills (e.g. group working, social interaction and problem solving skills as well as learning how to use equipment or programs; often related to making video) or content knowledge. Mostly learning was defined by student learning alone, but in some instances learning included everyone involved, students and teachers alike.

Table 1. Advantages of PBL

<table>
<thead>
<tr>
<th>Advantage</th>
<th>n=99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning of students or teachers</td>
<td>63</td>
</tr>
<tr>
<td>Collaboration and a sense of community</td>
<td>57</td>
</tr>
<tr>
<td>Motivation</td>
<td>55</td>
</tr>
<tr>
<td>Student-centred learning</td>
<td>44</td>
</tr>
<tr>
<td>Versatility for education</td>
<td>35</td>
</tr>
</tbody>
</table>

Many teachers valued collaboration and a sense of community generated by PBL. Collaboration between teachers were found useful in practice:

“Teachers work together planning and teaching, sharing their pedagogical expertise and professional development” (Teacher 111)

“Belonging to a bigger entity has given structure to our project. The educators has had an opportunity to get peer support and ideas to own group project” (Teacher 103)

“Projects unified the whole school and added communality and we-atmosphere” (Teacher 2)

“Most beneficial has been social action, researching together and learning as a group” (Teacher 105)

“For the first time we tried co-teaching with four teachers. The subjects integrated were biology, chemistry and physics” (Teacher 17)

In addition, collaboration between classes and with other interest groups were found useful:

”Schoolwork and learning were made visible to parents (in StarT-day)” (Teacher 109)

”Collaboration between classes of different age students was enjoyable and important” (Teacher 24)

The motivation category includes all answers related to positive attitude change, building self-esteem, relevance, enthusiasm and getting excited or engaged in project working. Most of the cases were related to enthusiasm.

“The enthusiasm for project-based work was very infectious and initiated an actual snowball effect as the idea to pick Aronia berries for juice developed into a diverse market day!” (Teacher 11)

In the student-centered learning category most of the cases were about students being active learners, but also comments related to working in groups and taking different learners or students interests into account.

“The student have been planning, executing, documenting and doing self-, group- and peer-evaluation” (Teacher 21)
“Especially to gifted students StarT gave necessary challenges” (Teacher 21)

“They (students) liked the fact that they could choose the form and execution” (Teacher 78)

Versatility in education is a more heterogenic category compared to the others. Here are included all cases with possibilities for implementing curricula, teachers’ professional development, and using versatile teaching methods and learning spaces.

“The teacher was doing this kind of project for the first time and therefore development of instruction giving occurred during the process” (Teacher 41)

“Inspired by the new curricula, we wanted to develop teaching towards inquiry- and genuinely phenomenon-based learning” (Teacher 17)

“StarT brought joy and was truly in accordance with the new curricula as a transversal and phenomenon-based learning model” (Teacher 21)

4.2. Challenges of the PBL in practise

Teachers’ views on the challenges (Table 2) of implementing PBL were more coherent than view on the advantages of it.

Table 2. Challenges

<table>
<thead>
<tr>
<th></th>
<th>n = 99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilitating PBL</td>
<td>62</td>
</tr>
<tr>
<td>• time management</td>
<td></td>
</tr>
<tr>
<td>• project organization</td>
<td></td>
</tr>
<tr>
<td>• teachers’ skills</td>
<td></td>
</tr>
<tr>
<td>Technical issues</td>
<td>35</td>
</tr>
<tr>
<td>Resources</td>
<td>26</td>
</tr>
<tr>
<td>Student-related learning</td>
<td>23</td>
</tr>
<tr>
<td>Collaboration</td>
<td>20</td>
</tr>
</tbody>
</table>

Facilitating PBL was a challenge documented in most teacher responses. This includes all notions of teachers’ implementation skills, managing time for PBL and organizing project. These all relate to teachers’ pedagogical skills and their ability to facilitate PBL. The examples of the subcategories:

- Time management: “fitting time schedule (of StarT) to school working”
- Project organization “executing a project in small school requires a lot of effort and planning”, and “most challenging was finding ideas and creativity in planning”
- Teachers skills “I would do many things differently, if I now started again”, and “Doing (projects) raises feelings of insecurity on whether this is away from something important and are the content knowledge of curricula fulfilled”

Technical issues include challenges with ICT and documentation for StarT. “StarT reporting. Difficult and time consuming,” and “making video with non-existent ICT-skills”.
Although the lack of ICT equipment was not listed here, these cases were included in the resources category.

Lack of resources, mainly space, equipment and time, where reported. Cases in this category are things a teacher has less influence on.

Student-related challenges were motivational: “getting different learners engaged into working”, difficulties in guiding students: “student guidance in balanced proportions, so that you don’t restrict too much but give opportunities and offer tools” and students skills and knowledge: “The most challenging was to find suitable action that suited the students skills” “working in pre-set groups is not easy for everybody”.

The possibility to collaborate was often limited by time, as teachers experienced difficulty in finding a common time for planning.

5. CONCLUSION

To promote the use of PBL in instruction, it is useful to understand the advantages and the challenges teachers found its implementation in practice in order to design the different forms of support for teachers.

The teachers’ views recorded in this study are quite consistent with earlier research mentioned, such as Thomas (2010). PBL was found very useful in practice (see Table 1). The challenges (see Table 2) faced were mostly things a teacher can influence and take into account, such as facilitating PBL and ensuring learning. Often teachers reported lack of time being a major challenge (Mentzer et al., 2017), time referred to planning time with colleagues or the time consuming nature of project work in general. The latter is an issue a teacher can facilitate as are many of the challenges teachers reported. According to Bell (2010), thorough and careful planning is essential to the flow of the project and the success of the student. Unfortunately, teachers are reporting that they do not have sufficient time for this level of planning.

According to Blumenfeld et al. (1991), without adequate attention to ways of supporting teachers and students, these innovative educational approaches will not be widely adopted. The newer cognitively-based approaches that contemporary projects represent also require substantial changes in teachers' thinking about and dispositions toward classroom structures, activities, and tasks. PBL is not likely to work unless projects are designed in such a way that, with teacher support, they marshal, generate, and sustain student motivation and thoughtfulness.

The results found could be taken carefully account in preparing in-service training for teachers. Clearly, teachers need more training for supporting their pedagogical content knowledge (PCK) in PBL. Some teachers in StarT found collaborative learning and being a part of a community reaching beyond the limits of their school useful. The StarT programme in itself could be seen as a novel model for continuous teacher training in which 1) teachers pedagogical development occurs while facilitating PBL and working together with the students, other teachers at their school or other collaborators, 2) teachers have access to tested models for PBL and good teaching practices from other teachers as well as online instructions and training 3) participating teachers and schools are a part of StarT community, where learning is shared through workshops, science fairs and online voting for best projects as well as best teaching practices.

Because it takes time to learn to use PBL in practise, even two to three years for teachers to shift their understanding and teaching practices in teacher training (Mentzet et al.,
2017), there is a need for developing long-term or even continuous and collaborative models for teacher training. This should also include pre-service teacher training. If we want to engage more teachers in the use of PBL in future, more research is needed also to understand novice teachers’ use of PBL in practice.

REFERENCES


PREDICTING PERFORMANCE IN ELECTROCHEMISTRY USING CONCEPT MAPPING INSTRUCTION

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ABSTRACT

The main objective of this study was to determine whether students’ performance in the topic of electrochemistry can be predicted by concept mapping instruction through a software, while controlling for effects of gender and school type. A randomised pretest-posttest control group quasi-experimental research design was adopted. A sample of 400 form four students from secondary schools in Kakamega County, Kenya, with computer laboratories were selected through a multi-stage sampling technique involving purposive, proportionate stratified and simple random sampling techniques. A total of 10 teachers were selected and trained in concept mapping software. The dependent variable was academic achievement, while predictor variable was instructional method at two levels: Concept Mapping Software teaching and Conventional teaching. Gender and school type were controlled. Two achievement tests were used to collect data. The instruments were piloted to test their validity and reliability. Results indicated that they were valid and reliable for use. To test the hypothesis: H₀: Method of instruction does not predict performance in Electrochemistry, data were analysed both descriptively (using means and standard deviations), and inferentially, using sequential multiple linear regression with score on posttest as the dependent variable. Results showed that students’ performance in electrochemistry is not predicted by gender and school type. Method of instruction was a statistically significant predictor of performance in electrochemistry.

Keywords: Gender, School Type, Software Concept Mapping, Conventional Instructional Strategies, Electrochemistry, Achievement

1. INTRODUCTION

One of the roles of science education in the world is to develop in learners a sense of curiosity, which will help them understand how and why phenomena happen. Chemistry education specifically aims at inculcating in students a positive attitude towards appreciating the usefulness and relevance of scientific work in the world today (Iftekhar, 2013).

In Kenya, Chemistry education aims at providing knowledge that prepares learners for further study, vocations and to appreciate their environment (KICD, 2002). Chemistry can be viewed as a ‘bridge’ because it incorporates knowledge acquired from a variety of subjects like Physics & Biology, and has a wide range of applications in different fields like Medicine, Agriculture, Biotechnology and Engineering (Iftekhar, 2013; Masinde, Wanjala, & Michieka, 2015). A lot of emphasis is therefore placed on the application of the knowledge of Chemistry, in order to solve environmental and other issues that currently affect the Kenyan society. Teaching and learning of Chemistry continues to face different challenges globally.
In developing countries, the major problem is inadequate allocation of funds towards promoting quality teaching. In India for instance, the former prime minister, Dr. Mamhohan Singh announced in the 99th Indian Science Congress that his government would double the allocation of funds towards science education by the year 2017 (Iftekhar, 2013), which has already happened (Padma, 2015).

In Kenya however, the biggest problem currently lies in the consistently poor performance by students in the subject, in the annual Kenya Certificate of Secondary Education (KCSE) examination. Some of the reasons that have been attributed to this poor performance are; students’ low self-efficacy (Ministry of Education [MoE], 2015), low motivation (KNEC, 2014) and negative attitude towards abstract topics (Masinde et al., 2015).

All these factors boil down to the use of conventional instructional strategies of instruction, whose rampant use has been found ineffective, especially in abstract and difficult topics (Beck, 2009). A question-by-question analysis of previous national Chemistry examinations has revealed that topics which are abstract are performed much more dismally than those that are not. Electrochemistry is one such topic, which is very frequently tested, yet students perform very poorly in its test items (KNEC, 2016).

Software-Oriented Concept Mapping (SOCM) is considered superior to other forms of concept mapping in the sense that being an interactive computer-based approach, it stimulates creative thinking skills, improves communication skills, and at the same time keeping the learner up-to-date with their computer skills, which are much needed on the job market in the ‘digital’ world of today (Riga, 2015). It is a student-centred instructional strategy, which integrates technology to promote creativity in the way learners think about, visualise and relate different concepts in a topic or subject.

Implementation of SOCM in Kenya could therefore provide a timely intervention to the inappropriate and insufficient ways through which students have been learning electrochemistry and other abstract topics. It was expected that using SOCM alongside the Conventional Instructional Strategies (CIS), would be a breakthrough in promoting students’ self-efficacy, attitude, motivation, experimental skills and achievement, for good academic performance.

Elsewhere, this strategy has been found to impact positively on several aspects of students’ academic performance but unfortunately, research about its use in the Kenyan context is scanty at the moment and hence this study couldn’t be timelier. In fact, there is no study known to the researcher so far, about its application anywhere in Kakamega County. The current study was carried out to investigate the predictive effects of software-oriented concept mapping method of teaching on students’ performance, while controlling for gender and school type.

2. METHODOLOGY

A non-randomised pretest-posttest control group quasi experimental research design, was adopted. After pretesting both groups, the experimental group received intervention which entailed the use of SOCM by teachers, in teaching the topic of electrochemistry and students’ use of concept maps drawn on their own or with the help from their teachers, to revise electrochemistry out of class. Students in the control groups were also taught the same topic of electrochemistry through Conventional Instructional Strategies (CIS). Both treatment groups were t post-tested after the intervention. The study was carried out in Kakamega County, Kenya.
A sample size of n=400 was determined using the formula of Krejcie and Morgan while purposive sampling was used to select only schools that offer computer studies or those with computer laboratories to allow execution of the intervention SOCM. Thereafter, proportionate stratified random sampling was used to select type of schools: co-educational, boys’ only and girls’ only, to ensure representativeness of the sample. Six co-educational schools, two girls’ schools and two boys’ schools were selected.

Simple random sampling was further used to select only one of the form four streams from schools with multiple streams using the balloting technique. For schools with only one form four stream, the entire stream participated in the study.

Data were collected using two achievement tests: The Students’ Entry Behavior Achievement Test (SEBAT) as pretest and the Students’ electrochemistry achievement Test (SEAT) as posttest. The purpose of the SEBAT was to determine students’ entry behavior in Electrochemistry, so as to ascertain homogeneity. It was an 18-item, one-hour achievement test with a maximum possible score of 60 marks.

The SEAT was used to measure students’ understanding of concepts in Electrochemistry. It was a one hour achievement test whose items were set using a blueprint to enhance its face and content validity. The maximum possible score was 30 which converted to 100%. Cronbach’s α, a measure of internal consistency was computed using SPSS Reliability Analysis for each achievement test.

Results indicated that reliabilities were acceptable high (SEBAT, α=0.805 and SEAT, α=0.877). This confirms high internal consistency of the instruments and provides reasonable evidence that the items were consistently responded to in a like fashion.

A hierarchical multiple linear regression was used to test the null hypothesis. Students’ gender and school type were controlled. Descriptive statistics: mean and standard deviations were generated from the raw data, so as to give explanations to some of the observations and trends that emerged.

3. RESULTS AND DISCUSSION

Data collected were analysed descriptively and inferentially.

3.1 Descriptive Statistics

Descriptive analyses: means and standard deviations for the dependent measure (Performance) demonstrated a range of 10 to 90 (possible range 0 – 100) and no evidence of ceiling or floor effects (M = 54.59, SD = 11.89). The data are thus generally as accepted in terms of means and SD’s, and there are no out-of-bounds entries beyond the expected range. The experimental group performed better (M= 58.87, SD=11.08) than control group (M=50.31, SD=11.15). Significance of this difference was tested through conducting an inferential test.

3.2 Zero-order Correlations

Zero-order correlations were conducted. As applied to Multiple regression, zero-order correlations reflect the bivariate relationships between independent and dependent variables. The correlation coefficient reflects both the magnitude and direction of the relationship between two variables (LeBreton, Ployhart, & Ladd, 2004). Highlights of the zero-order correlation are presented in Table 1
Table 1. Zero-order Correlations for Students’ Performance in Electrochemistry and Predictor Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>SEAT</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance in Electrochemistry (SEAT)</td>
<td>400</td>
<td>1.000</td>
<td>0.007</td>
<td>0.026</td>
<td>-0.360</td>
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<tr>
<td>Predictor variable</td>
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<td></td>
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<tr>
<td>1. Gender</td>
<td>400</td>
<td>1.000</td>
<td>-0.229</td>
<td>0.080</td>
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<tr>
<td>2. SchType</td>
<td>400</td>
<td>1.000</td>
<td>0.012</td>
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<tr>
<td>3. InstrMethod</td>
<td>400</td>
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<td>1.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The correlations between the predictors (Gender, School type, and Instructional Method) and the dependent variable, SEAT which was measured through a posttest achievement test in electrochemistry, were small to moderate in strength, ranging from 0.012 (IM and SchType) to 0.360 (SEAT and IM) and statistically non-significant, which is good for a regression model. This indicates that the data are suitably correlated with the dependent variable for examination through multiple linear regressions.

According to Field (2009), a correlation of above 0.80 between two predictor variables is an indicator of possible multicollinearity issues. In this study, data collected did not violate the assumption for multicollinearity.

3.3 Primary Findings

The findings are related to the research objective and corresponding null hypothesis.

Objective: To determine whether method of instruction predicts performance in electrochemistry

H₀: Method of instruction does not predict performance in Electrochemistry

A sequential hierarchical multiple regression analysis was conducted in an effort to test the hypothesis that method of instruction does not predict performance in Electrochemistry. In hierarchical multiple regression, predictors are selected by the researcher based on past research and theory, meaning it is a theory-driven model (Field, 2009).

Gender and School type were controlled for by being entered in the first and second blocks. Method of instruction was entered in block 3 in order to see whether they add anything to the prediction over and above gender and school type.

Results are presented in Table 2. The initial model accounted for 21.2% of the variance in the student’s performance in electrochemistry ($R^2 = 0.131$, adjusted $R^2 = 0.125$, $p < 0.001$). Addition of IM as a third variable in the final model significantly improved the model fit ($ΔR^2 = 0.131$ $F_{\text{change}} (2, 364) = 59.487$, $p < 0.001$).

The results show significant positive regression beta weight for Instructional method ($β = -0.363$, $p < 0.001$), an indicator that students in experimental group performed better in the test, after controlling for the other variables in the model.
Table 2. Hierarchical Regression Analysis Predicting Performance in Electrochemistry from Method of Instruction (N = 400)

<table>
<thead>
<tr>
<th>Step and Predictor Variable</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>R²Adj.</th>
<th>ΔR²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>54.51</td>
<td>1.19</td>
<td>0.007</td>
<td></td>
<td>-0.002</td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>4.03</td>
<td>1.23</td>
<td>0.001</td>
<td></td>
<td>-0.004</td>
</tr>
<tr>
<td>SchoolType</td>
<td>-0.38</td>
<td>0.753</td>
<td>-0.026</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>0.783</td>
<td>-0.014</td>
<td>0.033</td>
<td></td>
<td>-0.125</td>
</tr>
<tr>
<td>SchoolType</td>
<td>-0.203</td>
<td>0.703</td>
<td>-0.014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>InstrMethod</td>
<td>-8.619</td>
<td>1.12</td>
<td>-0.363*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Means statistically significant predictor; ** Means statistically significant Model; Dependent Variable: POSTTEST SCORE

Both gender and school type were non-significant predictors of the students’ performance in electrochemistry (Table 1). Being non-significant predictors of performance in electrochemistry, gender and school type were excluded from the model. The final model was statistically adequate accounting for 12.8% of the variance of the student’s performance in electrochemistry ($R^2= 0.130$, adjusted $R^2= 0.128$).

Consequently, the null hypothesis of this study was rejected in favour of the alternative hypothesis. This implied that students’ performance in electrochemistry did not depend on whether or not they were male or female. Performance was also not influenced by school type.

4. DISCUSSION AND CONCLUSIONS

The findings of this study indicate that software concept mapping instruction is a superior method of teaching compared to the conventional method. Students who were taught by software concept mapping method had higher mean score in the performance test than those taught conventionally (Exp Group: $M= 58.87$, $SD=11.080$; $n=200$; Control group $M= 50.31$; $SD=11.15$; $n=200$). This implies that students can learn better when engaged in multiple representations during the learning process. It led to conceptual understanding of electrochemistry.

These findings are consistent with a recent study by Ogonnaya, Okechukwu, & and Ugama (2016), whose findings indicated statistically significant effects of concept mapping on students’ achievement in basic science. Results showed that concept mapping fosters students’ achievement in basic science than conventional methods. It is worthy to note that some inconsistencies also exist. Meltem and Serap(2004) investigated gender differences in academic performance in a Turkish university. They established that female undergraduate students outperformed their male counterparts during their college years. Additionally, they noted that while it was true that higher grades in the Faculty of Education and the greater concentration of female students in education departments helped explain the higher grades for the female students, it was also true that female students outperformed their male counterparts in all the other four schools considered in their study. Their multivariate analysis
further showed that controlling for all other relevant factors belonging to a certain school did not bring about an advantage to female students. This calls for further research in this area.

5. IMPLICATIONS

The findings of this study have implications for various stakeholders, namely students, teachers, teacher educators, and policy makers.

5.1 Students

Despite the limitations for this study, the results emphasise the importance of concept mapping in the learning of chemistry. The concept mapping is essential because it allowed students to gain meaningful learning. These findings lend support to the teaching of chemistry through concept mapping to enhance student performance and the learning experience.

5.2 Teachers

It appears in this study that software concept mapping bolstered conceptual understanding by enabling success; however, a longitudinal study investigating this possibility is needed to ascertain this possibility. Teachers should adapt methods to change both student self-perceptions and implement strategies to overcome conceptual understanding limitations.

5.3 Teacher Educators

Educators should consider integrating software concept mapping into instruction as a means to foster conceptual understanding. They should revise their curriculum for prospective teachers so as to incorporate software concept mapping as a method of instruction.

5.4 Policy Makers

The findings from this study have implications for policy makers. Curriculum planners need to develop a greater awareness and understanding of the various interactions involving the variables that predict performance in chemistry among high school students and thus integrate them in curricula. The findings have important implications for conceptual understanding and instruction. To design high school curriculum that aims to inculcate conceptual understanding of science concepts is thus required.

5.5 Implications for Further Research

We proposed extending our understanding of concept mapping as a predictor of performance in electrochemistry. It was revealed that concept mapping was a significant predictor. Further research is thus needed in teachers’ pedagogical content knowledge about fostering conceptual understanding in learning of electrochemistry and science generally. Future researchers may replicate this study with other data sources or a different population.

REFERENCES


ABSTRACT

This paper examines the use of structured inquiry-based assessments using a pilot sample with a quality assurance class. A comparison is carried out between assignments and tests separately when traditional methods of assessment are compared to structured inquiry-based methods of assessment. This structured inquiry-based approach positioned the student at the application stage on the statistical reasoning framework coupled with the relational step on the student observed learning outcome (SOLO) taxonomy. It was established that using inquiry-based assessments with the class led to significantly better student outcomes in both uncontrolled and controlled assessments.

Keywords: Inquiry-based learning, statistical reasoning, thinking and literacy, compartmentalised knowledge

SUMMARY

The main driver of this research was that students were arriving at AUT with a very compartmentalised knowledge of statistical concepts. As a consequence there were gaps in their knowledge in many cases of key statistical concepts. Students often don’t see the relevance of prior material because they compartmentalise knowledge by course, semester, professor, or discipline and so they don’t even think to bring that knowledge to bear. This compartmentalisation leads students to organise knowledge in a way that is very different from what’s required (Eberly Center, n.d.).

In addition very few students have had the experience of being assessed at once on a variety of concepts. Instead, their learning and assessment at school had been broken up into discrete learning areas called achievement standards. On entry we were requiring the students to have obtained a complete knowledge of basic statistical concepts from school so we can build on this knowledge and look at some real world applications involving one or more of these statistical concepts.

This research is important as it seeks to establish that an inquiry based approach to teaching and assessment will provide students with more chance of success in their studies as opposed to a teaching style format where each concept is introduced then specific tailored examples are used in order to progress from there. It’s envisaged that it will promote more interest in statistics and deal positively with student feeling about the lack of relevance of mathematics to the real world. The specific focus of this research involves two comparisons between assignment and test scores where the assessment tools were designed differently. One using an inquiry-based approach and the other using traditional methods. The quantitative data obtained from this pilot study of a complete class of 17 students was then analysed using graphs, statistical measures and Wilcoxon tests.
Results proved to be significantly higher when an inquiry based approach was used in assessment design as opposed to a traditional design. Changes in the quality assurance paper resulted as a result of this study. In addition the findings emphasised work done earlier supporting inquiry base learning and teaching approaches.

FRAMEWORKS

The following diagrams illustrate in order what an inquiry-based approach to assessment and hence the influence on teaching seek to overcome.

Figure 1. Fragmented Knowledge Domain

Figure 1 illustrates a typical student’s knowledge (statistical literacy SL) on entry to the quality assurance course where there are gaps in their knowledge. These students were largely non-mathematically inclined. They had come from a secondary school background where their knowledge had been assessed by achievement standards where concepts had been assessed separately.

Figure 2. Ideal Relationship

Figure 2 illustrates the ideal relationship between statistical reasoning, SR, statistical thinking, ST and statistical literacy, SL. A modification of this illustration was proposed by DelMas (2002). The thinking can only occur over the knowledge base whereas the SR required is a subset of the thinking where appropriate statistical concepts are used in context used and non-appropriate statistical concepts are rejected.

Figure 3. Actual Statistical Thinking
Figure 3 represents the actual statistical thinking required when confronted with an assessment task. In most cases the task requires knowledge which hasn’t been learnt previously and/or isn’t learned sufficiently enough from the teaching of the quality assurance course.

![Figure 4. Required Statistical Reasoning](image)

Figure 4 represents the actual statistical reasoning required in order to complete the assessment task. It forms a subset of the statistical thinking required but not a subset of the statistical literacy required. This gives rise to the necessity of finding a suitable linkage factor in order to compensate for the weaknesses in a student’s understanding of statistical concepts. This paper proposes that context is used based on an inquiry which is inherent in the assessment task. This is shown in Figure 5 where the assessment problem context overlaps the statistical literacy required. There are two mutually exclusive areas to be considered; P and K, where K represents statistical concepts known well enough and K’ represents statistical concepts not known well enough.

![Figure 5. Contextual Linkage](image)

The approach of this research is to bring in a contextual link to link these two mutually exclusive events by using an inquiry-based approach where the assessment task starts with the integrated problem reasoning stemming from the objective. This is illustrated by the bottom diagram in Figure 5.

**LEVELS OF INQUIRY-BASED LEARNING**

An integrated Assessment contains all levels of statistical reasoning. It permits the learner to demonstrate applied competence and which uses a range of formative and
summative assessment methods. According to Garfield (2002) we have the following levels of statistical reasoning:

- **Idiosyncratic Reasoning.** The student knows some statistical words or symbols, uses them without fully understanding them, often incorrectly, and may scramble them with unrelated information. This would amount to a student writing down some statistical words alongside their numerical values like mean, standard deviation and median but not making any use of these concepts towards solving the problem.

- **Verbal Reasoning.** The student has a verbal understanding of some concepts, but cannot apply this to actual behaviour. This is further down the track than idiosyncratic reasoning, with the student showing some understanding to what the mean, standard deviation and median measure, but they are not applied specifically in context to the problem being solved.

- **Transitional Reasoning.** The student is able to correctly identify one or two dimensions of a statistical process without fully integrating these dimensions.

- **Procedural Reasoning.** The student is able to correctly identify the dimensions of a statistical concept or process but does not fully integrate them or understand the process.

- **Integrated Process Reasoning.** The student has a complete understanding of a statistical process.

These five types suggest a hierarchical ordering of statistical reasoning with the successful completion of step 5 of this framework by the learner regarded as his ultimate goal in an inquiry-based teaching programme. Table 1 proposes a correspondence of instructional task words from Anderson and Krathwohl (2001) that have a suggested hierarchical ordering against five hierarchical levels of a statistical reasoning as proposed by Garfield (2002). Each category has action verbs attached to it that would be prevalent in a statistical analysis. Each reasoning category has been classified either as SL, ST and SR depending on its correspondence to the framework in Table 1.

### Table 1. Correspondence of Five Levels of Statistical Reasoning to Anderson and Krathwohl (2001)

<table>
<thead>
<tr>
<th>Level</th>
<th>Anderson and Krathwohl Task Words</th>
<th>Statistical Reasoning Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Remembering (1) Recognising</td>
<td>Idiosyncratic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knows SL</td>
</tr>
<tr>
<td></td>
<td>Understanding (2) Classifying</td>
<td>Verbal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Defines SL</td>
</tr>
<tr>
<td>3</td>
<td>Understanding (2) Interpreting</td>
<td>Transitional</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partial Understanding of where applied</td>
</tr>
<tr>
<td>4</td>
<td>Applying (3) Executing</td>
<td>Procedure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Application relating to inquiry context</td>
</tr>
<tr>
<td>5</td>
<td>Applying (3) Complete implementation</td>
<td>Integrated Process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Complete interpretation of all analyses relating to an inquiry</td>
</tr>
</tbody>
</table>
These five levels would be developmentally related in a statistical analysis pertaining to an inquiry. In this research, the framework correspondence starts at level 4 with the use of the task words applying and executing in the assessment instructions.

In matching up the level of inquiry required in the assessment with those proposed by Banchi and Bell (2008), structured inquiry would be the appropriate choice. Here students are supplied with the question and procedure (method), however the assessment requirement is to generate an explanation that is supported by the evidence collected in the procedure. In order to complete the assessment successfully the students need to explain the significance of the statistics generated by procedure. In defining the level of achievement required, a framework is shown in Figure 6 below.

![Figure 6. Structure of observed learning outcomes (SOLO Taxonomy)](image)

The structure of observed learning outcomes (SOLO) taxonomy is a model that describes levels of increasing complexity in student's understanding of subjects. It was proposed by John B. Biggs and K. Collis (1982).

This model consists of five levels of understanding:

1. **Pre-structural** – The task is not attacked appropriately; the student hasn’t really understood the point and uses too simple a way of going about it.
2. **Uni-structural** – The student’s response only focuses on one relevant aspect.
3. **Multi-structural** – The student’s response focuses on several relevant aspects but they are treated independently and additively. Assessment of this level is primarily quantitative.
4. **Relational** – The different aspects have become integrated into a coherent whole. This level is what is normally meant by an adequate understanding of some topic.
5. **Extended abstract** – The previous integrated whole may be conceptualised at a higher level of abstraction and generalised to a new topic or area.

Here by defining the objective at the start of the assessment tool we are kicking in at the relational stage with the context as the integrating factor. Most achievement standards in statistics would require a student outcome at the multi-structural stage. The assessment process being used is shown in Figure 7 where we start with the objectives and proceed in a clockwise fashion. In fact most of the previous assessments experienced by the students would have started with knowledge use and proceeded in an anti-clockwise fashion.
Along with the challenge of teaching statistics, there was another challenge of being able to design practical assessments having applications while at the same time, testing the knowledge of all the required basic statistical content. Part of this challenge has been in the design of a theme involving an inquiry situation to cover all of the questions in an examination. A large number of statistical concepts had to be tested and a possible application that could be linked to the theme had to be devised for each learning objective. With the advent of using unit standards for assessment involving workplace learners, there has been the need to examine a predetermined set of performance criteria expressed as learning outcomes. According to Yilmaz (2004), the overall ability to use statistics can be assessed against three competencies:

- The ability to link statistics to a range of contexts,
- Knowledge of basic statistical concepts, and
- The ability to synthesize the components of a statistical study and to communicate the results in a clear manner.

All three of these competencies would be important to assess as they need to be applied both to solving a problem and in communicating the outcome so all could understand. Employers look for problem solving skills (applications to real world), communication (clearly articulate statistical ideas and interpretations) – 2 of the three major items the third is working in a team. The identification of learner deficiencies in various elements of statistical reasoning will be essential as a key step in improving both teaching strategies using inquiries and assessment tools. Various elements of statistical reasoning allow connections to be made between basic statistical concepts and real world applications. There is then the clear communication of findings in order to satisfy a report objective.

RESULTS AND ANALYSIS

This section displays the results as Table 2 obtained by the pilot sample where two differently designed assignments and two differently designed tests were compared. Assignment 1 and 3 combined were based on a traditional structure while assignment 2 was based on an inquiry. Assignment 2 tracks the process of a Quality Assurance programme at LabPlus, a diagnostic laboratory that tests blood samples. The test was based on the quality assurance of a kiwifruit packing house whereas the exam was based on a traditional exam structure. A traditional structure is taken to mean an assessment that has several contexts where the student response required only focuses on one relative aspect corresponding to the uni-structural level of understanding.
Table 2. Comparative results

<table>
<thead>
<tr>
<th></th>
<th>Assign 1 &amp; 3</th>
<th>Assign 2</th>
<th>Test</th>
<th>Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>66.17</td>
<td>80.00</td>
<td>40.00</td>
<td>36.92</td>
</tr>
<tr>
<td>100</td>
<td>69.50</td>
<td>80.00</td>
<td>62.00</td>
<td>56.92</td>
</tr>
<tr>
<td>100</td>
<td>96.00</td>
<td>100.00</td>
<td>100.00</td>
<td>90.77</td>
</tr>
<tr>
<td>100</td>
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<td>95.00</td>
<td>94.00</td>
<td>87.69</td>
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<td>100</td>
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<td>76.00</td>
<td>70.77</td>
</tr>
<tr>
<td>100</td>
<td>71.17</td>
<td>90.00</td>
<td>80.00</td>
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<tr>
<td>100</td>
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<td>90.00</td>
<td>70.00</td>
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<td>80.00</td>
<td>62.00</td>
<td>58.46</td>
</tr>
<tr>
<td>100</td>
<td>74.00</td>
<td>90.00</td>
<td>64.00</td>
<td>55.38</td>
</tr>
</tbody>
</table>

The histogram of all 64 scores (Figure 8) showed normality verified by the Kolmogorov-Smirnov Test with \( p = 0.6735 > 0.05 \). However with the individual sample sizes at 16, I opted for a non-parametric test so the Wilcoxon signed rank test (Altman, 1991; Conover, 1999) was used. Also the Wilcoxon test took into account that the data was paired.

Figure 8. Histogram of combined scores
Table 3 below shows some summary statistics.

<table>
<thead>
<tr>
<th>SUMMARY</th>
<th>Assigns 1 &amp; 2</th>
<th>Assign 2</th>
<th>Test</th>
<th>Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>72.4069</td>
<td>86.5625</td>
<td>69.1250</td>
<td>59.3263</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>11.6560</td>
<td>8.7023</td>
<td>16.9071</td>
<td>17.9325</td>
</tr>
<tr>
<td>Median</td>
<td>70.2500</td>
<td>90.0000</td>
<td>67.0000</td>
<td>56.9200</td>
</tr>
</tbody>
</table>

In comparing assignments, the Wilcoxon signed rank test confirmed that the mean of assignment 2 was significantly higher than that of assignments 1 and 3 combined to a high level of significance (V = 131, p = 0.0001526 < 0.01). Also the mean for assignment 2 was much higher and the scores were more consistent.

In comparing the test with the exam the Wilcoxon signed rank test confirmed that the mean of the test was significantly higher than that of the exam to a high level of significance (V = 103, p = 0.007278 < 0.01). Also the mean for the test was higher than the exam however the exam results were more consistent.

For the controlled assessments the scores were significantly correlated (r = 0.62925 > 0.4972 at 5% level of significance) which reflects reliability with respect to ability in statistics. However for the uncontrolled assessments the scores weren’t significantly correlated (r = 0.37123 < 0.4973 at 5% level of significance). This reflects the differing conditions under which uncontrolled assessments are attempted by the students compared to controlled assessments. Students tended to do better on some parts of assignments compared to other parts so there was a lack of consistency. However the comparison is still valid.

CONCLUSION

This quality assurance paper contained several real world applications where a process could be followed through completely and several statistical concepts were “in play”. This meant that the teaching which preceded the assessments could follow an inquiry-based approach.

This research showed that the results were significantly better when structured inquiry-based approaches were used in both the assignment and test assessments. It can be concluded that contextual links do play a positive role in a student’s ability to recall information about statistical concepts and hence increases their ability to apply that information to the problem at hand.

The student’s understanding would move between relational and multi-structural on the SOLO Taxonomy (refer Figure 7). By seeing the application relating to inquiry context at level 4 on the statistical reasoning framework, the student would then move to interpreting the statistics at level 3 then back to applying at level 4 (refer Figure 6).

Finally then we can conclude that these contextual links allow a student to see the purpose before the application is decided upon. Hence the method is more likely to be remembered by the student in order to complete the problem.
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MATHEMATICS: TO INTEGRATE OR NOT?

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ABSTRACT

Poorly designed integrated STEM curricula treat mathematics as a tool, generally limited to simple concepts. This paper uses two case studies to argue that mathematics cannot be learned exclusively within an integrated STEM program. In one example mathematics was taught in the context of a science topic and in the other mathematics was taught as a stand-alone subject based on big ideas, using a wide range of contexts. They showed that where STEM contexts determine the way that mathematics is taught, there was an ad hoc and narrow approach to the teaching of mathematics. In contrast, the stand-alone mathematics program that used any engaging real-life context was more successful in providing the necessary depth and breadth. The paper concludes that an integrated STEM pedagogy must be supplemented by the stand-alone development of the big ideas of mathematics, using any context that engages students.

Keywords: Mathematics, STEM, integration, big ideas

INTRODUCTION

In recent years, many countries have focused intensively on science, technology, engineering, and mathematics (STEM) education programs. The Queensland Curriculum and Assessment Authority (QCAA) supports STEM programs as a way of acquiring deep knowledge of STEM subjects while developing skills in creativity, problem solving, critical thinking, and communication (QCAA, 2018). The strong relationships between STEM subjects have been identified by many authors, including Chalmers, Carter, Cooper, and Nason (2017), who examined these relationships in terms of shared big ideas. The big ideas of STEM are the central, organising ideas (Schifter & Fosnot, 1993) that robustly link many different understandings into a coherent whole (Charles, 2005). Chalmers et al. (2017) identified three types of big ideas of and about STEM: within-discipline big ideas that have application in other STEM disciplines, cross-discipline big ideas, and encompassing big ideas.

The connections between the knowledges and skills of STEM have led to the development of integrated STEM curricula (Johnson, Peters-Burton, & Moore, 2016). However, the development of integrated STEM curriculum units that foster deep learning of and about STEM has proved to be challenging (Berland, 2013; English, 2016; Honey, Pearson, & Schweingruber, 2014). In many instances, schools developed these programs by inserting elements of technology and engineering into existing science and mathematics units. However, even where the programs are integrated, the four disciplines often exist as separate elements within the program (Moore et al., 2014).

Poor design of integrated STEM curriculum units is potentially detrimental to in-depth student learning (Chalmers et al., 2017). Mathematics and engineering are generally under-
represented in these programs (English, 2016) and students are not challenged to engage in the construction of meaningful mathematics (English, 2016; Pruet, 2015). This occurs because not all mathematics can or should be learned within an integrated program (Honey et al., 2014). Individual components of STEM within integrated programs, particularly mathematics and engineering, have been “dumbed down” as the teaching focus moves from knowledge construction to application (Cooper, Carter, & Lowe, 2016; English, 2016).

Chalmers et al. (2017) theorised that the big ideas of and about STEM can be used as a framework for the development of integrated STEM curriculum units. This paper investigates this in two case studies, focusing particularly on the teaching of mathematics:

1. a case study of an attempt by a Queensland secondary school to use an integrated approach to the teaching of STEM; and
2. the approach used by YuMi Deadly Mathematics (YDM) that teaches mathematics as a stand-alone subject.

AN INTEGRATED APPROACH

This first case study is based on the experience of one of the authors of this paper, teaching in a large secondary school using the Queensland curriculum. The school decided to trial an integrated approach to the teaching of STEM. It quickly became obvious that the full integration of the subjects was not possible because:

- There were no teachers with skills in teaching all four areas of STEM. Apart from the obvious implications for the effective delivery of the curricula, this posed problems for the safe supervision of practical work in laboratories and workshops.
- In the short term, the school timetable prevented the integration of the different disciplines, although this could have been remedied by a timetable redesign in the following school year.
- Whilst mathematics and science were compulsory subjects, engineering and technology concepts were largely taught in elective courses, selected by relatively small numbers of students. The school had a basic computing skills program for all students. The elective nature of some courses affected the extent of prior student knowledge that could be assumed and made it difficult to design a course that provided challenge in engineering and technology for all students.

Accordingly, it was decided to integrate tasks, rather than classes. Each discipline had a different, mandated curriculum so the task had to provide opportunities to cover the curriculum content of them all. The science department proposed that a Year 9 marine ecology unit would allow the development of skills in statistics (mathematics) and spreadsheeting (technology). However, there was little scope for engineering concepts. A team of senior teachers in science, mathematics, and computer studies collaborated in writing the task. There was no discussion of the big ideas of STEM in planning the task. Whilst it met all the objectives for the science course, the context did not provide opportunities for the comprehensive coverage of the Year 9 statistics and spreadsheeting objectives. For example, students were required to collect, tabulate and graph data and visually identify trends, but were not required to compare data displays using measures of location and spread.

The composition of mathematics, science, and computer skills classes differed. All students had different teachers for the three subjects. Accordingly, the task was presented in a single workbook that students could take to each class.
The task was required to contribute to the assessment of students in all three subjects. However, each subject had its own mandated assessment criteria, with little overlap. The school expectation that the assessment methods were transparent to students added to the workbook complexity. Each teacher assessed the work in their own subject, so the grading task was administratively complex, with completed workbooks moving from teacher to teacher and then returned to students, with re-sorting required at each stage.

After a review of the completed experiment by the teachers involved there was universal agreement that students gained little from the integration of the units of work. It was felt that any benefits were outweighed by the failure to adequately cover the Year 9 curriculum in the other subjects and the considerable increase in teacher workloads. The experiment was not repeated.

This case study is illuminating for two reasons. First, it provides an example of the pedagogical and curriculum issues that arose when the task was designed around a science context (marine ecology). The result was a failure to comprehensively cover the relevant parts of the mathematics program (statistics). Second, it reveals the effect of school administrative processes on the successful integration of STEM subjects – an often-overlooked issue.

THE STAND-ALONE APPROACH

The second case study relates to YuMi Deadly Mathematics (YDM), a pedagogical approach to the teaching and learning of mathematics as a stand-alone subject. YDM is based on the big ideas of mathematics that cover significant concepts, have a wide effect, and provide the basis for more efficient and effective learning of mathematics (Cooper et al., 2016). It uses real-life contexts of relevance to students as vehicles for student engagement. It aims to develop the pedagogical skills in mathematics teachers to make their teaching meaningful and interesting to students in order to increase student engagement and mathematics understanding. YDM uses four phases: reality, abstraction, mathematics, and reflection (RAMR; Cooper & Carter, 2016). Thus, it begins with students’ real-life contexts and ends with reflecting back to their reality while linking mathematical concepts through big ideas across topics and years (see https://research.qut.edu.au/ydc/about/yumi-deadly-maths/).

While the YDM approach can use aspects of STEM as examples for the application of mathematics, it is not limited to these disciplines because this would restrict the opportunities to develop mathematical concepts in other contexts that are meaningful to students. It also does not require teachers to be skilled in STEM to provide contexts for the application of mathematics. YDM takes a more comprehensive approach than most STEM programs because it aims to connect the mathematics with any student interest, using a real-life context to which students can easily relate.

Since 2009 YDM has worked with over 1000 teachers in more than 250 schools Australia-wide. This case study is an example of the implementation and outcomes of YDM in 14 schools that completed up to 2.5 years of YDM professional development (PD) workshops and school visits focusing on big ideas and a real-life contextual approach to the teaching of mathematics.

Quantitative data on PD workshops, classroom implementation and outcomes of the YDM approach were collected from school principals and teachers participating in the case study. The workshops, which emphasised the need to connect the mathematical big ideas to real-life contexts, were given a mean rating by participants of 4.2 on a five-point scale (1=not
useful; 5=very useful; n=548). Online surveys conducted every six months demonstrated the effectiveness of the broadly-based contextual approach to the teaching of mathematics. Both teacher surveys (n=46) and principal surveys (n=60) noted moderate increases in teachers’ confidence in teaching mathematics as well as in their mathematical knowledge and pedagogical skills. This increased teaching capacity was reflected in student outcomes: 88% of teacher survey responses (n=128) reported increased student engagement, 75% reported improved student learning and understanding, and 30% reported better test results.

Qualitative data in the form of teachers’ reflective journal entries describe the effectiveness of using a broad range of real-life contexts, including Indigenous contexts, in the teaching of mathematics. One teacher wrote:

We were doing a lot of things the indigenous students might be accustomed to. So – stories … a family on an island who were having a gathering … They needed to get to the mainland but the barge could only take 20 people and there was 25 … they [students] were like “aww Miss sometimes one of my families mum or dad catches the barge and they go and get groceries on the mainland”… they could understand how that would relate.

The teachers particularly commented favourably on the benefits of using the real-life contexts to illustrate the big ideas of mathematics, for example:

How powerful YuMi is with the students and how vital the basic big ideas are to students and satisfying … guidelines to change the curriculum successfully.

We are in a lucky position to be able to use the YuMi big ideas as the basis of our number curriculum.

This case study shows the value of teaching mathematics in a way that captures the interest and motivation of students by linking the mathematics back to their own reality. Increased engagement and improved mathematics learning, understanding, and test results were evident when teachers adopted an approach that tapped into students’ areas of interest. It demonstrated that any meaningful context can be used to improve outcomes, not just those with connections to STEM. The case study also demonstrated the success of a stand-alone approach in developing the big ideas of mathematics in a comprehensive way.

DISCUSSION

The two case studies differ in the approach taken to the teaching of mathematics, either integrated with STEM studies or as a stand-alone subject.

Depth

In the integrated approach, a science context determined the content taught in mathematics and technology. Mathematics was used as a tool to achieve the required science outcomes. This view of mathematics as a tool is implicitly endorsed in the recent statement of the Chief Australian Scientist that “mathematics is the language of science” (Finkel, quoted in Koziol, 2018). However, when the science context determines the mathematics content, it is often limited to low-level skills that are not relevant to the mathematics curriculum for that year level (Pruet, 2015).

Even where the STEM context requires high-level mathematics, the coverage of the mathematics curriculum may be inadequate. For example, the mathematical big ideas of rate of change and area are rarely developed into differential and integral calculus within STEM
contexts, even in physics where calculus is a valuable tool. While physics may provide the context, there is a need to develop the underlying mathematical concepts first.

The second case, which develops the big ideas of mathematics through real-life contexts as a starting and end point for the development of mathematics concepts, led to a much deeper understanding of mathematics.

**Breadth**

Another difference between the two cases is the breadth of the contexts used to teach mathematics. The integrated approach was limited to STEM contexts to teach mathematical concepts. In contrast, the stand-alone approach allowed the use of any context that was relevant to the curriculum and engaged the students in mathematics learning. Using life-related contexts that are broader in scope and often more relevant to students than STEM contexts, such as shopping, money and personal finances, sports and culture (including music, art, and dance), increases the opportunity to use big ideas to link mathematical concepts across topics.

From a mathematics perspective, it follows that if only STEM contexts are used to exemplify mathematics concepts, there is a risk of an ad hoc and narrow approach where only those mathematical skills used by other STEM elements are developed. This results in a lack of rigour and gaps in the delivery of the mathematics curriculum (Berland, 2013; English, 2016; Pruet, 2015).

**School processes**

The first case study also demonstrated that a successful integrated STEM approach requires school policies, procedures and resources to be considered in addition to pedagogical issues. This may require whole school change.

Anecdotal evidence suggests that, like the case study of the integrated approach, many schools that experimented with forms of STEM integration have reverted to an approach of teaching some aspects of mathematics (at least) as a stand-alone subject. This has occurred because integration was too hard to implement, and/or the integrated approach did not adequately cover the mathematics curriculum. Accordingly, Silk, Higashi, Shoop, & Schunn (2010) recommend that explicitly promoting the role of mathematics by focusing on the mathematics content and temporarily reducing the emphasis on other STEM content (that is, a stand-alone approach) is one way in which mathematics pedagogy might be advanced.

**CONCLUSION**

This paper has argued that real-life contexts are essential to the teaching of mathematics. However, the effectiveness of an integrated STEM program in teaching mathematics has its limitations. In cases where the primary focus is on the context and not the underlying big ideas, mathematics is reduced to a tool to achieve a particular outcome. If the contexts of an integrated STEM program determine how mathematics is taught, it may be limited to only those skills used by other STEM elements, with a resultant loss of depth and breadth in the delivery of the mathematics curriculum. Although not examined in this study, it may be that this conclusion applies to the other STEM disciplines, for example, if the mathematics curriculum determines how the science is taught, the coverage of the science curriculum may be limited.

Even if school administrative processes allow for an integrated approach to the teaching of STEM, there is a need for some teaching where the primary aim is to develop the big ideas of mathematics, using any context that engages students. This is likely to require the inclusion of stand-alone mathematics lessons within the STEM program. The many
connections between STEM disciplines, whilst reinforcing understandings across the disciplines, should not be used as an argument for the same pedagogical approach to all STEM elements.

REFERENCES


ROBOTICS AND COMPUTATIONAL THINKING FOR PRIMARY SCHOOLS

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ABSTRACT

This qualitative study examined how six Australian primary school teachers (Years 1-6), from four schools, introduced robotics in their classrooms and how this helped develop their students’ coding and computational thinking skills. Data were collected from surveys, on-going reflective journals, and semi-structured interviews. The findings indicate that using the LEGO® WeDo 2.0 robot kits and the accompanying guides, helped build teachers’ confidence to implement robotics-based coding activities in their classrooms. The teachers reported that the robotics offered opportunities to introduce young students to coding and computational thinking. Students’ involvement in the FIRST® LEGO League Junior robotics program also helped develop their problem-solving and teamwork skills. The teachers in this project developed a greater awareness of computational thinking and an increased confidence in their ability to teach relevant robotics-based coding activities. The study identified that further research needs to be done in this area and teacher professional development should focus explicitly on how to teach developmentally appropriate robotics activities that further promote computational thinking concepts, practices, and perspectives.

Keywords: Technology, Robotics, Computational Thinking, Coding

INTRODUCTION

The benefits of using robotics in education have been reported at all levels of schooling. Robotics activities can promote collaboration and teamwork and provide a tangible way to understand abstract ideas (Bers, 2008). The application of Science, Technology, Engineering, and Mathematics (STEM) concepts in robotics contexts can capture young students’ interest and build their aspirations for future STEM studies (Nugent, Barker, Grandgenett, & Adamchuk, 2010). This increased interest leads to improvements in students’ mathematics and science understandings (Barak & Zadok, 2009) and provides opportunities for teachers to introduce students to computational thinking (Atmatzidou & Demetriadis, 2016).

Computational thinking involves designing systems and employing abstraction, sequencing, and problem-solving skills (Barr & Stephenson, 2011). Specific computational thinking skills include: (1) abstraction, (2) generalisation, (3) decomposition, (4) algorithmic thinking, and (5) debugging (Angeli et al., 2016). These computational thinking skills are essential for students to understand in order to participate in the technological world in which we live (Wing, 2006). Angeli et al. (2016) introduced a computational thinking framework aimed at introducing children, aged six to 12, to computational thinking skills through the use of problem-solving tasks. According to the framework, students develop the skills of abstraction and generalisation as they transfer their understanding from one solution to another by identifying familiar patterns; they develop decomposition skills as they
breakdown complex problems; and use algorithmic thinking to devise sequences of steps to be executed. The iterative problem-solving process also involves students using debugging skills as they identify and fix issues and errors.

Other frameworks have been proposed to help assess the development of students’ computational thinking concepts, practices, and perspectives (Brennan & Resnick, 2012). Computational thinking concepts include programming ideas such as sequencing, switches, variables, and loops. Computational thinking practices are the problem-solving and iterative approaches taken during the testing and debugging of software programs. Computational perspectives are the ideas formed by understanding “the world around them and about themselves” (Brennan & Resnick, 2012, p. 1) and include developing positive attitudes about problem solving with technology and working through issues and problems. Students can adopt a computational perspective by seeing themselves as producers and designers rather than just consumers of technology (Voogt, Fisser, Good, Mishra, & Yadav, 2015).

Robotics can be an effective way to introduce computational thinking as it involves students being able to sequence the coding commands needed to program a robot. Concepts and attitudes relevant to computational thinking need to be developed in primary school (Wing, 2006) and even young children can be introduced to easy-to-use visual programming tools and robotics platforms that can help develop coding and computational thinking skills (Bers, Flannery, Kazakoff, & Sullivan, 2014). However, Bers, Seddighin, & Sullivan (2013) warn that many early childhood teachers lack the experience and have limited knowledge of how robotics technology can be implemented in the classroom. Previous research studies have mainly focused on how robots can be used to develop computational thinking skills with upper primary and secondary school students (Voogt et al., 2015). More research still needs to be done on effective ways to introduce these ideas and how young children can learn the skills.

Teacher education and support is needed to build teachers’ understanding about developmentally appropriate pedagogical approaches to learning with robots (Bers, 2008). Previous studies on robotics and computational thinking in primary school have concentrated on students; only a small number of research studies have focused on teachers and issues concerning the integration of robotics in primary school classrooms (Yadav, Gretter, Good & Mclean, 2017). This research study addresses this limitation by focusing on teachers’ perceptions of the value of integrating robotics-based activities for developing students’ computational thinking skills.

Robot kits

The WeDo 2.0 robot kits, used in this study, introduce primary school students to hands-on learning through constructing with LEGO® bricks and coding with the graphical programming software. Students code with the software and physically build the robot; providing students with a “hands-on, minds-on” learning experience (Scaradozzia, Sorbia, Pedalea, Valzanoc, & Verginec, 2015). The software also provides guides and videos so students can be scaffolded through the activities as they construct their robots and use the graphical programming software to create their robot programs. This allows teachers to expose students to basic science, engineering, and computational thinking concepts at an early age (Strawhecker & Bers, 2015). The eight WeDo 2.0 Guided Activities (Pulling, Speed, Robust Structures, Frog’s Metamorphosis, Plants and Pollinators, Prevent Flooding, Drop and Rescue, Sort to Recycle) and eight WeDo 2.0 Open activities (Predator and Prey, Animal Expression, Extreme Habitats, Space Exploration, Hazard Alarm, Cleaning the Ocean, Wildlife Crossing, and Moving Materials) include supporting teacher guides with
videos, activity ideas, assessment templates, and links to the Australian curriculum. The WeDo 2.0 kits are also used in the FIRST LEGO League Junior (FLL Jr.) robotics program.

**FIRST® LEGO® League Junior**

FIRST (For Inspiration and Recognition of Science and Technology) LEGO League Junior (FLL Jr.) is an international robotics program for teams of two to six children (aged 6-9). The program helps build students’ aspirations for future STEM studies and helps build teamwork and problem-solving skills. Guided by their teachers, students create “Show Me” posters and produce a working motorised model using LEGO WeDo 2.0 to present their solutions to a real-world problem (http://www.juniorfirstlegoleague.org/).

**METHOD**

This study used a multiple-case study design to examine how teachers implemented the robotics activities in their classrooms and to investigate their perceptions of the value of the activities for developing students’ coding and computational thinking skills. A multi-case study approach was adopted because it involves data collection from natural settings (e.g., classrooms) and allows the use of multiple cases for comparative purposes (Stake, 2006). The research questions for this study were:

1. How do teachers incorporate the WeDo 2.0 robot kits and FLL Jr. within their classroom lessons?
2. What do teachers perceive of the value of robotics activities for developing primary school students’ coding and computational thinking skills?

**Participants**

This study involved six teachers, (Years 1-6) from four primary schools, introducing LEGO WeDo 2.0 robotics kits in their classrooms. Five teachers were teaching in Years 1-3 and one teacher in Years 3-6. The teachers had varying levels of teaching experience, ranging from one year to 14 years, although only one teacher had classroom robotics experience. The teachers were part of a larger robotics university outreach program and the participating teachers indicated their interest in using the WeDo 2.0 kits. Three of the five teachers in the Year 1-3 group also registered teams for FLL Jrn. Each participating teacher was provided with 15 robot loan kits, with the accompanying software and teacher guides. The teachers explored and experimented with the kits and decided how the robot activities would be integrated in their classrooms.

The teachers were asked to complete an initial survey to find out their ideas about robotics and their perceptions of the role of robotics in primary school classrooms. Using a 5-point Likert scale, participants could choose to strongly agree, agree, be neutral, disagree, or strongly disagree with the 20 statements on the survey. The survey statements were based on the studies of Bers et al. (2013) and Mundy, Kupczynski, and Kee (2012). Each teacher kept a reflective journal on how the WeDo 2.0 kit was used in the classroom and if and how students engaged with FLL Jr. The teachers completed the journal reflections following the implementation of each WeDo 2.0 activity. The teachers were asked to reflect on how the activities assisted students learning coding and computational thinking skills. The follow-up semi-structured interviews were conducted during the last week of the study to gain further information on the teachers’ perceptions of the benefits of using the WeDo 2.0 robotics kits and the FLL Jr. activities. The interview questions were based on Bers et al. (2013) study and related to teachers’ perceptions of the benefits of using robotics in early years classrooms.
RESULTS AND DISCUSSION

Adopting the computational thinking frameworks from Brennan and Resnick (2012) and Angeli et al (2016) three core themes (concepts, practices, and perspectives) were identified from the data. Computational concepts identified included sequencing, loops, and pattern recognition. Students developed a computational thinking perspective as they iteratively engaging in computational practices as they problem solved and debugged their programs and robot constructions. The teachers all commented that students were developing computational skills as they made adjustments and improvements to their robot construction or coding. The participants identified computational thinking concepts including pattern recognition, loops, and sequencing when describing how students worked with their WeDo robots. For example, one teacher commented: “I think they definitely learned that it’s a process and that you need to send the right message. So you have to have the right sequence to get it to work”.

The teachers also mentioned the computational thinking process was important for students as it helped students to work through problems. Learning to code with tangible systems such as robots helps children develop the ability to correctly sequence and debug their programs (Angeli et al., 2016). For example, while one class of students initially had difficulties debugging their programs, the teacher reported that the students worked through it:

And they were starting to show those higher order thinking skills ...where they knew this is the way it should work and this is how it should work and they were starting to go through and eliminate, Maybe this is it, no it’s not.

Students also engaged in iterative problem solving as they tested out their ideas for the FLL Jnr. challenge. The participants reported the main benefits of students’ involvement in FLL Jnr. as increased student engagement and improvements in students’ problem solving. The teachers emphasised different aspects of problem solving in their comments ranging from students learning the iterative nature of the design cycle to persistence with problem solving. The FLL Jnr. showcase also allowed students to work towards a goal and celebrate their learning. As one teacher stated: “With FLL it’s always great to celebrate what you’ve done so I think that was a really great celebration for them...just the way they wanted to put the effort in made me really proud of them”.

The teachers considered both FLL Jr. and the WeDo 2.0 activities to be developmentally appropriate for their students. One teacher stated that they were developmentally appropriate due to the way the activities were scaffolded, the program used a visual block coding, and the students constructed their robots with appropriately sized LEGO bricks: “Yes, I did think they were because of the way they’re scaffolded and everything. The colour block coding, the size of the Lego, it was engaging for them”. The teacher with the Year 3-6 class did adjust some of the WeDo 2.0 activities to include extra engineering challenges to further engage the older primary school students. The teacher stated that it was important to extend students so that they understood: “One the function of the code and two, the idea that it’s got to be connected to that physical, the code represents a physical aspect of your build”.

All participants in this study reported improvements in students’ teamwork. The teachers stated that students became less reliant on the teacher as they became more confident in their problem solving and were able to share their solutions with other teams. One teacher noted: “Students surprised me at how quickly they picked it up, how well they worked together and how well they were helping other teams as well”. To address their own lack of
familiarity with the software the teachers adopted a problem-solving approach where they learnt alongside their students. For example, one teacher stated: “I’ve learned a lot even about the programming and the kids have taught me which is even better”.

Lack of technical knowledge and lack of support has been identified in relevant literature as a potential challenge for teachers implementing robotics in their classroom (Khanlari, 2016). Teachers also need to be aware of computational thinking skills and how to teach them explicitly (Angeli et al, 2016). One of the main themes to emerge from this study focused on the teachers’ concerns about their lack of knowledge about robotics and computational thinking. For example, one teacher stated that after being involved in the study: “I feel like I’ve got a bit of a clue now…. I still don’t know nearly enough. But it’s made me want to know more”. Angeli et al. (2016) point out that computational thinking is relatively new to teacher education programs and most teachers lack the understanding of how to teach computational thinking skills. All teachers in this study, however, showed a willingness to implement the WeDo 2.0 robot kits in their classrooms and all reported that they had developed their confidence to teach robotics-based coding activities.

CONCLUSION

The results of this study demonstrate that exploring with and using the WeDo 2.0 robot kits and activities helped build teachers’ confidence and knowledge to implement robotics-based science and technology activities in their classrooms and introduce primary school students to computational thinking skills. All teachers reported that using the WeDo 2.0 robotics kits offered unique opportunities for developing coding and computational thinking skills; focusing on activities that promoted problem solving and group work. Student involvement in FLL Jnr. further developed their problem-solving and teamwork skills. The teachers in this project developed an awareness of computational thinking skills and an increased confidence in their ability to teach relevant developmentally appropriate robotics activities. While the teachers reported that they and their students were developing computational thinking skills, important aspects were raised in this study regarding teachers’ knowledge about computational thinking. A greater awareness of relevant concepts, practices, and perspectives would assist teachers to embed computational thinking and developmentally appropriate robotics activities in primary school classrooms.

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HUMANOID ROBOTS: PROGRAMMING AT SCHOOL

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ABSTRACT

This paper reports on a study that is part of a three-year research project investigating how NAO humanoid robots were used in early childhood, primary, and secondary school settings and what teachers and students learnt by working with these robots. This qualitative study focuses on three case studies, from the three schools settings, to explore how the NAO humanoid robots were incorporated in the classroom, how teachers and students engaged with the robot, and what computational thinking skills students working with the humanoid robot developed. A multiple case study design allowed for an exploration of the use of the humanoid robot in the different school settings as well as a comparison between settings. Multiple forms of data were collected from ten teachers, across the three schools, in order to gain their views and to enable the teachers to discuss their experiences and perceptions on using the humanoid robot in their classrooms. The findings indicate that humanoid robots can be useful across a range of schools settings, have a positive impact on students engagement, and can not only help develop students’ computational thinking, but can also help develop other 21st century skills.

Keywords: Technology, Robotics, Humanoid, Computational Thinking, Coding

INTRODUCTION

While numerous research studies suggest that robotics activities have a positive effect on learning outcomes and can help develop computational thinking, the introduction of humanoid robots is relatively new to schools and pedagogical approaches are still being trialled. More needs to be known about how teachers incorporate humanoid robots in the classroom; about how students engage with these robots; and how humanoid robots can help students develop coding and computational thinking skills.

Coding and programming are terms that are used interchangeably, however, Lye and Koh (2014) argue that programming is more than just coding. Coding is generally understood as the technical skills required to use a programming language (Angeli et al., 2016). Programming is a broader term that includes the application of computational thinking concepts (Brennan & Resnick, 2012). Computational thinking is essential for 21st century learning and includes thinking skills and finding creative ways to solve problems (Wing, 2006). According to Wing (2008), “computational thinking involves solving problems,
designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science” (p. 33).

Essential computational thinking skills for programming include: problem decomposition, algorithmic thinking, testing, and debugging (Yadav, Mayfield, Zhou, Hambrusch, & Korb, 2014). Problem decomposition involves breaking complex problems into smaller familiar problems that are more easily solved (Atmatzidou, & Demetriadis, 2014). Students use algorithmic thinking to find the most efficient algorithm by planning and programming a sequence of steps and they problem solve when things go wrong with the program (Wing, 2006). They are also involved in recognising when their program is not meeting the goal and attempting to solve the issues (Bers, Flannery, Kazakoff, & Sullivan, 2014). These computational thinking skills are developed when students create and code programs for humanoid robots (Keane, Chalmers, Williams, & Boden, 2016).

This paper reports on a study that is part of a three-year research project investigating the impact of the NAO humanoid robots on students’ learning and the pedagogical approaches that enhance and extend learning (Keane et al., 2016). The project examined how these humanoid robots were used in early childhood, primary, and secondary classrooms and what teachers and students learnt by working with these robots. Two NAO humanoid robots were used in the selected schools for a period of 8-11 weeks. The NAO robot is 58cm, in human form with two arms, two legs, a body and a head. The robot’s movements and sensors, such as sight, sound, touch and social behaviours, can be programmed using the accompanying easy-to-use Choregraphe© drag and drop visual programming software.

The study focuses specifically on three case studies in order to address the following research questions:

1. How do teachers and students engage with humanoid robots in the classroom?
2. How does working with humanoid robots help students develop coding and computational thinking skills?

METHOD

Multiple case study design (Simons, 2009; Stake, 1995) was selected to investigate the use of the humanoid robots in different school settings. Multiple case study design approach allowed for exploration of the use of humanoid robots in each setting as well as a comparison between the settings. While case studies do not have statistical generalisability between settings, they can have theoretical generalisability due to the links made between theory and evidence (Yin, 2014).

Participants and context

Three schools were selected from the three-year project, representing early childhood, primary and secondary school settings, in order to give greatest variation in settings for the research data. The adoption of humanoid robots in schools depends on teachers’ perceptions of the usefulness of the robot for educational purposes (Fridin & Belokopytov, 2014) so ten educators were involved in this study, across the three schools. Prior to the receipt of a robot, the teachers were provided with two days of professional development (PD) consisting of programming support and a discussion of teaching strategies they could use.

For this study each school was considered as a separate case study from the perspective of the “qualitative or naturalistic research paradigm” (Merriam, 1988, p. 3). This perspective emphasises the experience of the participant with a focus on qualitative analysis (Yin, 2014). In order to achieve “data triangulation” (Yin), multiple forms of data were collected from
each school using questionnaires, reflective journals and semi-structured interviews, to contribute towards the development of a richer in-depth understanding of the whole phenomenon (Creswell, 2008).

The questionnaire consisted of 24 open-ended response questions aiming to provide information on how the NAO robots were used in the classroom, the challenges faced and teachers’ perspectives on whether humanoid robots have a place in the curriculum. Scaffolded reflective journals were used to help teachers reflect on the use of the robot and about how the activities were conducted. The participants were also asked to provide suggestions for other teachers exploring ways to integrate humanoid robots within the curriculum. Semi-structured interviews were used to collect teachers’ responses to their experience working with the humanoid robot in the classroom.

RESULTS

Case study 1

The setting for this first case study was an early childhood centre involving 3 educators [April, Peta, George], from Pre-Foundation (4-5 year olds) and Year 3. In each class the humanoid robot was used to generate interest and extension in the area of computer science and robotics. The interactions with the robot also allowed 4 and 5 year old children to develop a deep understanding about robots. April (Pre-Foundation) stated “the children’s thinking about robots deepened every week. We worked on constructing robots, making design plans before constructing a robot and discussed theories about how robots work”.

Peta and George (Year 3) reported that all students loved having the humanoid robot in the classroom and they were excited when they were working with the robot. With the younger students (4-5 year olds), April stated that many students were initially hesitant to touch the robot but slowly built up their confidence when they saw other children interacting with the robot. Some students treated the robot as a human from the start and presented the robot with small gifts, drew pictures, and read stories. In the Pre-Foundation class, a discussion about a robot having feelings led to a discussion about how robots work and if robots could be programmed to have feelings.

All students were able to develop algorithmic thinking, even the 4-5 year old children. For example, Peta stated that the Year 3 students worked with the younger children to help them “design their own coding sequence on paper using string to join the sequence together”. The Year 3 students were then introduced to the Choregraphe software and mastered the drag and drop coding to complete the planned sequences. George reported that some students wanted to focus specifically on the technical aspects of the robot. For example, students wanted to know how the robot would “work without wifi” and what applications could be used to control the robot.

Case study 2

The second case study involved three teachers [Betty, Zack, Carol]; Betty used the NAO robot in German language classes for students in Foundation to Year 7, and Zack and Carol used the robot with literacy rotations with students in Year 6 and 7. In the German language classes, students were involved in a variety of activities that developed from the teacher showcasing the pre-programmed German language program to developing, testing, and debugging their own programs. Betty reported that students would review the vocabulary they were learning through games and activities then “they wrote programs to make her talk in German and move her body parts. She was a tool for their learning”. 
During the literacy rotations Year 6-7 students were introduced to the Choregraphe software and Carol stated that they were “shown how to create basic sequences and how to create a Timeline”. Students “thrive on the freedom to learn and play with certain features at their own pace”. Zack reported that students spent time “watching videos, reading blogs and wikis, and doing research on how to do things” and “their understanding grew, mostly self directed, of how they could use the code and software, even some Python [programming language] to get Pink [NAO robot] to do things”. The students in the Year 6-7 classrooms recorded their problem solving journey in video journals on iPads as they worked with the robot, including “how it went, challenges faced, and next steps or goals”.

The teachers reported that students interacted with the robot in different ways. Zack stated that younger students treated the robot “like a special class visitor, they smile and talk to her a lot. They copy her actions and sing along with her. Older students love the novelty of Pink, they speak to her nicely, treat her with special care and enjoy working with her”. Betty commented “younger students treated her like a peer, someone to talk to and interact with. They copied her actions and seemed fascinated with what she could do. Older students were more interested in what and how she worked. They wanted to see what they could make her do”. Zack stated that the teacher became more of a “coach in helping them [students] shape their goals and expectations, and giving suggestions” and students involved in the activities with the humanoid robot were “very self-directed and enjoyed helping and collaborating with each other”.

**Case study 3**

Three teachers from lower secondary classes in a Year 7-12 co-educational secondary school informed the last case study [Hannah, Anne, Simon]. The robot was integrated into Year 8 Mathematics and German language classes and a Year 7 general studies class. In the language classes, students gave verbal commands for the robot, while students in the coding club (Years 7-10) designed and created the program. In mathematics, students investigated computational thinking and how programming the NAO could enhance their understanding of algorithms. Hannah stated that the NAO robot was used for various activities in the Year 7 class, including using the robot as part of a website they created on ancient China or India. The robot “had to feature on the page and provide some information about their civilisation”. Students also used the NAO robot to share information “With the entire cohort and parents. She was a feature of their stall and shared information about what they had learnt”. Other activities included students following the robot performing yoga and Tai Chi session in Health lessons and students creating their own dance programs for the robot to follow.

The teachers reported that there was a high level of excitement and engagement with the robot. Anne stated, “The robot applications proved a hit with some of the more reluctant students”. Simon indicated surprise at the affection demonstrated for the robot and stated that many students saw the robot as a human child; a small friend or a younger sibling. Hannah reported that students were also enthusiastic to collaborate with their peers and share their knowledge of the software “it has been amazing to observe students collaborative and problem solving skills with the technology”.

Problem-solving skills were developed while students were engaged in basic and sophisticated programming. They were successful in approaching the learning of concepts through a computational thinking approach. Simon commented, “firstly, to programme NAO to perform a task the task must be broken down into steps and an algorithm designed”. Simon further commented that programming with the robot “really stretches those students who excel in conventional education” as these students have a tendency “to give up because instant success just doesn’t happen”. Trouble-shooting with the robot helped students
develop resilience when faced with a problem. Simon mentioned key themes such as “curiosity, persistence, engagement, and self-directed learning” when describing how students were programming the NAO robots.

DISCUSSION

There was evidence that there were multiple ways students engaged with the programming activities. The visual programming software used to program the humanoid robot used in this study provided a range of entry points for students from 4 years of age to Year 10 and provided an opportunity for differentiated, self-directed learning to take place. The teachers commented that students persevered with working with the robot, as they were intrigued about how they could make the humanoid robot emulate the tasks they had designed. Teachers also commented that they had underestimated the depth of the relationship students would develop with the humanoid robots.

The teachers in the study reported that the humanoid robot sparked students’ interest in coding and robotics. The perseverance shown and the complexity of students’ coding also made teachers see their students in new ways. As students engaged more with the robot, they tried more complex programming and took risks as they tried to achieve their vision of what they wanted the robot to accomplish. Students developed an understanding of coding as they experimented with the visual programming software and as they continually refined their coding in order to achieve their goals.

As students’ computational thinking skills developed, they experimented with programming the humanoid robot by building on their own and others’ ideas. The procedural thinking needed for programming was developed over a number of different activities that helped develop students’ understanding. A number of skills in this study were identified that are similar to the computational thinking concepts identified by Yadav et al. (2014). Students were able to achieve success with programming the robots by using computational thinking skills including Problem decomposition, Algorithmic thinking, Problem solving, Testing, and Debugging.

Teachers in this study noted that student learning extended well beyond the expected skill level for their age in computational thinking and coding. Being able to code and problem-solve with robots and other technologies are important skills that need to be developed (Atmatzidou & Demetriadis, 2014). Programming the robot helped learners extend their computational thinking skills. The students in this study used the humanoid robot’s drag and drop programming software and in some cases students went further and self-taught themselves Python, a high level programming language used by many professional programmers. Even young students learnt how to program the robot by sequencing paper-based, instructional icons.

CONCLUSION

This study indicates that humanoid robots can have a positive impact on not only developing students’ coding and computational thinking skills, but also other 21st century skills. This suggests that humanoid robots may be useful for learning and teaching purposes across a range of school settings. While the findings confirm previous research conclusions that robots engage students, the use of humanoid robots in schools has been recent. The next stage of this research will consist of investigating students’ perspectives on the use of humanoid robots across a range of learning areas. As such, future research will continue to
build on understanding of the impact of this innovative technology in a rapidly changing educational landscape.

REFERENCES


ABSTRACT

STEM education for the future requires maximising learning opportunities by making connections with industries that utilise technologies. Machines, in particular, have become integral in the medical sector. For example, machines have been used to advance radiation treatments on patients. This qualitative study investigates one link between education and industry as a way to connect real-world activities for students in the classroom. Specifically, an industry partner (Radiation Oncology Centre – ROC) has consulted with university personnel at Queensland University of Technology (QUT) for designing and constructing a model of a radiation machine (linear accelerator). The purpose is to provide a model for first-time patients into a Radiation Oncology Centre as a way to allay concerns about the radiation machine. Data collection included: (1) first-hand account of a radiation machine, articulated by two radiation therapists and a patient; (2) brief provided by QUT educational personnel for fourth-year university student engagement in the model design and construction; (3) observation data from staff involved in the model design and construction, and (4) photographic images of the model. Radiation therapists will be able to talk with patients about the machine by using the model. Conclusions are drawn about the benefits of forging partnerships with industry for designing purposeful education in schools. Indeed, teacher education must advance understandings though real-world examples to ensure the next generation of school students are substantially informed about technologies.

Keywords: STEM, machine education, teacher education

BACKGROUND, GOALS AND OBJECTIVES

STEM education is a new endeavor for Australian schools and with the inclusion of engineering education it has the potential to engage students in STEM. Nevertheless, the development of STEM education units of work for primary/secondary requires exploration and evaluation. The purpose of this paper is to evaluate the planning, preparation and implementation of STEM education with particular attention to design, including connections with curriculum documents, conceptual development considerations, and resources required in preparation for teaching STEM education.

Over the last decade or so, Australia had engaged in programs where STEM education was evident. For instance, between 2005 to 2007 there were 83 projects that combined the STEM areas (Department of Education, Science and Training, [DEST], 2007), however these projects occurred between groups of schools and organisations. The Melbourne Declaration (2009) outlines the need for a world-class education and presents, mathematics, science and
technology though does not mention engineering. MYCEETYA’s (2009) four-year plan also supports the Melbourne Declaration with developing students’ education across a range of subject areas, including mathematics, science and technology; yet it too omits incorporating engineering education as part of STEM. Although Australian Curriculum (ACARA, 2014) does not include engineering education, it can be positioned within and across the curriculum (Hudson, English, & Dawes, 2014) and may have further connections with the technology curriculum.

Australia’s Chief Scientist (2014) argues strongly for the need to build STEM capacity with evidence that high performing countries embrace STEM and claims Australia is falling behind as a result of not including STEM education across all sectors. The call is for Australian education to “prepare a skilled and dynamic STEM workforce, and lay the foundations for lifelong STEM literacy in the community” (p. 20). There is a decline for a few decades in the number of high school students wanting to study in the STEM areas in Australia (Lyons & Quinn, 2015). However, formative stages of planning and preparing for teaching STEM education require analysis within this relatively new educational field.

The main goals and objectives of this paper include: (1) demonstrating a practical university-industry partnership; (2) inspiring initial teacher education (ITE) students enrolled in a STEM elective unit to make real-world connections to industries; and (3) enlightening ITE students in ways for planning and implementing education programs that may connect with real-world opportunities.

THEORETICAL FRAMEWORK & METHODOLOGY

This qualitative study used constructivism as an epistemology with interpretivism as the theoretical perspective that draws upon a case-study methodology (see Crotty, 2003; Denzin & Lincoln, 2011). Participants (final-year initial teacher education students) constructed ideas socially (Vygotsky, 1978) to design and construct a model of a radiation machine. Interpretivism was used by the researchers from data collection methods: observation, interviews and end product (i.e., model of radiation machine). In this interpretive, single-case study, the analytics included participant perceptions of their learning while engaged in the model design and construction.

In the first phase of this project, one researcher (Chandra) observed participant construction of the radiation machine model. The observation also included how the participants worked and the types of discussions presented. In the second phase, interviews will be conducted with 5-6 students enrolled in the STEM unit. The end product (model) was analysed by one researcher (White) in terms of replicating the real-world radiation machine held at a Radiation Oncology Centre (ROC) and its usefulness for patient education.

The context for the investigation involved a ROC patient, who is also a researcher (Hudson), providing FaceTime information to the class of final-year students (participants) about the purpose of the model. Additional information was provided by the ROC therapist (White), which included providing pictures and videos of the radiation machine. It was assumed that providing a real-life context would further motivate the participants in their involvement in the project and towards achieving their coursework aims. The final-year students were involved in a STEM unit within their teacher education degree. The model design and construction aligns with science, technology, engineering and mathematics (STEM) subject areas. These students had opportunities for social interaction to uncover meanings about designing and constructing a model representation and the STEM activity was considered a way to target their zone of proximal development (ZPD, see Vygotsky, 1978).
The STEM unit in this instance was an elective that was offered to final year students who were enrolled in the Bachelor of Education (Primary and Secondary) degree program. Most of the students had limited knowledge on how an integrated approach to teaching STEM could be implemented in their future classrooms. Thus, one of the primary objectives of the unit was to immerse the students in activities where they would get an opportunity to explore real world design challenges and then draw upon their STEM knowledge and skills to implement feasible solutions. The design challenges within the activities were strategically identified across two dimensions in terms of the appropriateness and complexity (Markauskaitė & Goodyear, 2014). In the first half of the semester, the final-year students were immersed in activities which enabled them build solar ovens to cook paninis, propose ideas for the track layout for a model railway township, and create the fastest paper planes. They also engaged and interacted with real world entrepreneurs and inventors. Following this interaction, these guests presented the students with wicked problems such as designing a bike helmet that minimised impact with the head during an accident. Within this mix of problems, the students were challenged to create a model of the radiation machine.

RESULTS AND DISCUSSION

Although further results will be forthcoming, the following provides an indication of the results. A brief was provided by the first author to the final-year university students for their engagement in a model design and construction activity. The second author outlined the design challenge and the need for this device at the ROC. He provided an overview of why such technology was crucial in the treatment of cancer and how it impacts on patients’ lives. To illustrate, according to the radiation therapists, most new cancer patients enter the ROC without knowledge of how the radiation machine (linear accelerator) works. Creating a working model that simulates the radiation machine may help to alleviate fear in patients. This model can be used by therapists to explain how the machine works, particularly with the scientific details about the radiation measure, target areas and the value of CT scans attached to the machine.

The first author instructed the students in the group to brainstorm ideas on how a model could be built. They also had to take into consideration the durability of their proposed designs. The final-year students engaged in online research to explore ideas. One of the students in the group responded with ideas that formed the basis for further analysis. The student proposed the following: This is a file of a 3D model created of a LINAC machine, this file is open source and Creative Commons which means we will be able to use it within an educational space. See the weblink: https://www.thingiverse.com/thing:1018097. This is a webpage from TinkerCAD, an app that supports computer assisted drawing and developing coding skills. It links to developing 3D models into Lego and the app can be used with primary students (see https://www.tinkercad.com/bricks). This page gives a more streamlined approach to converting 3D files into Lego (e.g., https://brickify.it/). Finally, this article links to a programmer who looks at the structural integrity of LEGO structures if they are converted from 3D (see https://gizmodo.com/mad-genius-develops-lego-algorithm-to-build-any-3d-obje-647181411?IR=T

There was no funding to develop this model. However, in a workshop that followed, all students in the group were asked to analyse the ideas proposed in light of the durability and cost. Collectively the group decided on the first option because it was the most durable and the least expensive. More importantly, there was a staff member at QUT who was willing to build a prototype of the model using his 3D printer (Figure 1, four perspectives of the model).
The model was built and shipped to ROC for comment, including how the model may serve their purpose and any improvements to the design that might facilitate a better understanding of the radiation machine.

CONCLUSION AND SIGNIFICANCE OF THE STUDY

The study demonstrates a practical way to connect education with industry, thus in this study a partnership was forged for the purposes of connecting university education to a real-world experience. Observations and student comments indicated that the initial teacher education (ITE) students were motivated as a result of making real-world connections to industries. The ITE students were able to plan an education program that may assist school students in classrooms. Conclusions are drawn about the benefits of forging partnerships with industry for designing purposeful education in schools. Indeed, teacher education must advance understandings though real-world examples to ensure the next generation of school students to be substantially informed about technologies.

REFERENCES

ABSTRACT

Computer-based problem solving assessment is an important reference for measuring students' problem solving competency. Compared with traditional pen-and-paper tests, it can record students' entire cognitive process, and make the evaluation more comprehensive and effective. PISA established computer-based problem solving assessment, but it didn’t evaluate students’ ability of extracting information quickly. In this article, we concluded the rules of item designing for computer-based problem solving assessment and introduced a unit designing of our own which was named “The earthquake rescue team”. When designing items, we should firstly create the context, and the context needs to be closely related to students’ real life, rather than require a lot of professional knowledge from problem solvers. It should also be fully integrated with computer technology and have some significance of education. Secondly, the interface of unit needs to be designed. The information presented on the computer screen mainly included: title, unit’s statement and operational guidelines, interactive area, item’s presentation, answer area, and various function buttons. In addition, we also need to provide some information for students, including useful and illusive information. Next, we should design items corresponding to four different cognitive processes. Item designing needs to be consistent. Besides, how to design summative evaluation needs also to be considered in a compete computer-based problem solving assessment design.

Keywords: Problem solving competency, computer-based assessment, item designing

1. INTRODUCTION

STEM education aims to develop students’ competency to adapt into society, such as interdisciplinary literacy and problem solving competency. The existing evaluation on STEM education’s effect usually concentrates on students’ learning results. Most of the evaluation are traditional assessments (e.g., pen-and-paper closed quizzes) and performance assessments (e.g., interviews, self-reports, task results presentation, and reflection journals) (Jiang & Cai, 2017).

These evaluation methodologies are mainly targeted at knowledge level and skill level, and the skill evaluations are subjective, it usually depends on mutual evaluation and teacher evaluation. Therefore, generalising the problem solving evaluation mechanism and use it on STEM evaluation can make STEM evaluation more objective and effective.

The traditional pen-and-paper problem solving assessment can only record the answer; it’s difficult to record the entire cognitive process when students solve the problems. Computer-based problem solving assessment can solve this problem effectively. The interactive computer-based problem solving assessment can record students’ problem solving
process, facilitate more comprehensive analysis and evaluation of students' problem solving competency. Problem solving assessment involves individual problem solving assessment and cooperative problem solving assessment. This paper aims to discuss rules of item designing for computer-based individual problem solving assessment.

2. LITERATURE REVIEW

Problem solving is caused by certain situations, and is a process in which a problem is tackled according to certain goals, with the application of cognition activity, skill and so on, and after a series of thinking operation (Anderson, 1985). It can be divided into four stages: (1) the initial representation of the problem (the understanding of the problem); (2) develop problem solving plans and find solutions to problems; (3) the representation of the reconstruction problem (a further understanding of the problem); (4) execute the plan or test results (Glass & Holyoak, 1986). This pattern reflects the nonlinear characteristics of problem solving (Yuan & Wu, 2010).

On the basis of this theory, we can divide the cognitive process of problem solving into four categories: exploring and understanding, planning and executing, representing and formulating and monitoring and reflecting (Organization for Economic Co-operation and Development [OECD], 2013).

A well-known problem solving assessment project is PISA (Program for International Student Assessment), which was initiated by OECD. Problem solving assessment is one of its assessment projects. PISA established computer-based individual problem solving assessment on the basis of pen-and-paper problem solving assessment in 2012. PISA mainly constructs the content of students' individual problem solving competency from three aspects: the diverse problem background, the interactive nature of problem situations, and the multi-level problem solving process (Chen, 2015).

As for the diverse problem background, the content of the assessment mostly come from students' unknown life issues, and solving these problems often require knowledge of various disciplines rather than a single-disciplinary knowledge. As for interactivity, students can interact with computers, and computers can capture and record students' behavioral data such as the frequency of clicks, the sequence of operations, etc. Students’ problem solving process involves four categories: exploring and understanding, representing and formulating, planning and executing, and monitoring and reflecting. In order to ensure the reliability and validity of the assessment, the items for PISA 2012 problem solving assessment came from two sources: the PISA Consortium and national submissions. The expert group that developed the PISA 2012 framework reviewed all materials to ensure that they reflected the defined construct of problem-solving competence. The items were then reviewed by national centres and field tested (OECD, 2014).

Through reading articles from past years, we can conclude that the research into computer-based problem solving assessment mainly stays in the theoretical stage. There is no mature research on specific item designing rules for computer-based problem solving assessment. Besides, PISA problem solving assessment focuses on recording and evaluating students’ cognitive processes, but does not evaluate motivations and emotions (OECD, 2013). From analysing the units of PISA, we can find PISA do not examine students' ability to collect information quickly; but in fact, an information-processing view of personal problem solving involves the way people take in information, process that information into plans for solutions to personal problems and carry out those plans (Heppner, & Krauskopf, 1987). So we wanted to design an assessment that can not only try to assess problem solving competency from a general aspect, but also evaluate problem solving competency from the
perspective of quick learning and information extraction. At the same time, the topics we
choose are more focused on attitude and emotion educational areas such as health and safety,
in order to guide students’ values to some extent. Therefore, concluding a set of rules for the
assessment of our own is of practical significance for related research of computer-based
problem solving assessment.

3. RULES OF ITEM DESIGNING FOR COMPUTER-BASED PROBLEM SOLVING
ASSESSMENT

In terms of structure, item designing of computer-based problem solving assessment
mainly includes creation of context, designing of interface and designing of items for
different cognitive processes. As is shown in Figure 1.

![Figure 1. Process of item designing](image)

PSAA is a computer-based problem solving assessment platform which was developed
by the Advanced Innovation Center for Future Education. According to these rules, our team
designed a unit of computer-based problem solving assessment which was named “The
earthquake rescue team” on the PSAA platform.

3.1. Creation of Context

When creating context, we need to consider four aspects. Firstly, the context need to
related to students’ daily life. Secondly, we should avoid too many professional knowledge
requirements for students, because problem solving assessment focuses on evaluating
students’ ability to use exciting conditions to turn unknown into known. Thirdly, we should
give full play to the advantages of human-computer interaction. Finally, context settings
should have educational significance, such as safety education, health education, etc.

We created a context where some rescue issues needed to be arranged after an
earthquake in “The earthquake rescue team”. Earthquake is a problem that students often hear
about in their lives. When solving these kinds of problems, students may face many unknown
knowledge, and so it can test students’ competency of using clues to seek solutions. Many
situations under this context require computer simulation technology. When solving this
Earthquake problem, students can gain knowledge on rescuing, and develop safety
awareness.

3.2. Designing of interface

For each item, the information presented on the computer is mainly divided into five
parts: title, operational guidelines, interactive or answer area, item’s presentation, and
various function buttons. Besides, sometimes we need to provide some information for
students to help them in solving problems. The operational guidelines need to clearly explain
what interactions needed to be done to complete the task and what changes can occur by
these interactions. For the interactive area, specific interactive methods need to be determined, such as which variable can change by dragging a certain slider. Sometimes the interaction area can also be directly used as the answer area. Item presentation can be divided into item description and item requirement. Item requirement describes what students need to do, what actions need to be performed, or what results can be obtained. Item description provide conditions or restrictions. For example, the interface of “Repairing and sorting of lines”, which is an item of “The earthquake rescue team”, is shown in Figure 2.

Figure 2. Repairing and sorting of lines

With regards to the interface of this item, the operational guidelines introduced how to interact with the system. It stated that students can click the red part to repair the equipment. The item description presented some restrictions. It stated that the electricity was cut off in Cuxh and it takes two hours to repair a distribution room and one hour to repair a line. Only one place can be repaired at a time. The item requirement required students to use the best solution to restore power. Operational guidelines and item’s presentation are hidden when students compete the task, and can appear by clicking on a special symbol. Restart and give up are two function buttons.

Particularly, in order to provide necessary information for students, we set up an “Information Center” as an additional resource. Some of the information provided here is helpful for students to solve problems, while the rest are interference information. Therefore, students must extract useful information from many messages, and the frequency and time that students view the information will be recorded as part of the evaluation.

3.3. Item designing for Different Cognitive Processes

Each item corresponds to a certain cognitive process. Next, we will discuss the designing of items which corresponding to different cognitive processes.

3.3.1. Exploring and understanding

Exploring refers to exploring the problem situation through observing or interacting with it, finding information and restrictions. Understanding refers to understanding given information and relevant concepts while interacting with the problem situation. When designing this type of items, the item description provides some specific process or information, and the item requirement asks students to judge the possible results caused by the process or information.
For example, the item of “The earthquake rescue team” related to this process was “Determine the level of emergency response”. For this item, the item description gave the magnitude of an earthquake. The “Information Center” related to this item gives the full text of the National Emergency Response Plan. The item requirement asked students to judge the level of emergency response according to the information which was given by the item description and the “Information Center”. So students need to judge the result by finding information of magnitude and understanding the relationship between magnitude and emergency response level which was given by the “Information Center”.

3.3.2. Planning and executing

Planning consists of goal setting and making plans or strategies to reach the goal. Executing consists of carrying out a plan. When designing items, the item description was the result of a possible behavior, and the item requirement asked students to achieve this result through planning operation.

For instance, the item description of one item of “The earthquake rescue team”, named “Selecting rescue route”, was: “The garment market has been seriously damaged in the earthquake. There are a large number of wounded people who need emergency assistance. Medical personnel are now dispatched from the hospital”. The item requirement was: “Please collect the required information and choose the fastest driving route”. We can see that the item description provided a certain result, that is, go from the hospital to the garment market. The item requirement asked students to choose the right one from many different roads through planning operations so that the required goal can be achieved in a certain order. The distance between each place was given in the “Information Center”. When executing, students need to correct the answer repeatedly in order to solve this problem. Figure 3 shows this item.

![Selecting rescue route](image)

**Figure 3. Selecting rescue route**

3.3.3. Representing and formulating

Representation emphasises the use of tables, graphics, symbols, oral representations and other forms to organise problems; thus, items related to this cognitive dimension need to be designed in conjunction with the above forms.

At the same time, combined with the requirements of formulating, which refers to formulating hypotheses by identifying the relevant factors in the problem and their interrelationships, organising and critically evaluating information, we can ask students to
make some assumptions associated with context. For example, the item requirement could ask students to describe a particular phenomenon or process, or use tables or figures to make assumptions about a certain aspect of the context, and then ask students to judge it.

For instance, the item “Classification of wounded” is as shown in Figure 4.

For this item, we provided many wounded cases with different degrees of injury, such as “there is trauma to the head, breathe 20 times/min, have pulse and can listen to instructions”, etc. This item required students to classify the injured using START (Simple Triage and Rapid Treatment). Students need to judge the degree of injury suffered by the wounded and use symbols (tapes of four different colors) to patch the wounded in order to represent their ideas. Steps of START was given in the “Information Center”.

3.3.4. Monitoring and reflecting

Monitoring refers to monitor the progress of achieving goals in the process of problem solving. Reflection refers to finding solutions from different perspectives. When designing an item, the item descriptions is the result of a possible behavior, the item requirement asks students to achieve this result by literal description or actual operation.

In addition, it is necessary to provide students with feedback during the process of problem solving. Students need to find the best strategies for all given constraints according to the feedback provided by the system. The influence of conditions, goals, and feedback on students' problem-solving process is shown in Figure 5.

Figure 4. Classification of wounded

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Figure 5. Influence of conditions, goals, and feedback on students' problem solving process
For example, the item “Flight route” is as shown in Figure 6.

![Figure 6. Flight route](image)

For this item, it is required that the relief supplies be dropped into five towns (A, B, C, D, and E) before dark. The upcoming rescue helicopters can only fly straight in the direction of southeast and northwest. Whenever the helicopter advances a square, the time will be a little less, and up to 20 squares would dark.

The figure in the upper right corner records the number of squares the helicopter has passed, so students are always monitoring their problem solving process and they can adjust their route according to the figure all along. If the figure in the upper right corner reaches 20, the feedback will prompt as shown in Figure 7. It tells students that they have taken 20 steps, but they failed to rescue the five cities. The students will then need to reflect on which of the steps they took needs to be adjusted according to the feedback received and the given conditions. Students can then restart.

![Figure 7. Flight route](image)

Throughout the entire designing process, all items should be consistent, so that the conditions or conclusions of the previous item can be applied to the next item. All items should be designed as a spiraling process in terms of difficulty and complexity. In order to ensure the reliability and validity of our items, our designing team contains experts. After designing, we conducted multiple rounds of tests in many schools. The results showed that the items can effectively reflect the problem solving competency of students.
4. CONCLUSION

Computer-based problem solving assessment can examine whether students have the competency to use cognitive strategies to solve unknown problems. Its popularity is conducive to the improvement of the effectiveness of STEM assessment. PISA established computer-based problem solving assessment in 2012. But it did not evaluate students’ competency of extracting key information. Rules of item designing for computer-based problem solving assessment include creation of the context, designing of the items and correlation between the items.

The context needs to be closely related to students’ real life, not requiring much professional knowledge for students, fully integrated with computer technology, and have some significance to education. The information presented on the computer mainly included: title, operational guidelines, interactive or answer area, item’s presentation and various function buttons. Item designing differs for different strategies namely exploring and understanding, planning and executing, representing and formulating, and monitoring and reflecting. Finally, we should focus on the coherence of items and provide scaffolding for students, such as the “Information Center”. In order to evaluate students’ ability to extract key information, the “Information Center” often contains some illusive information.

Our research focuses on rules of item designing for computer-based problem solving assessment, but it does not involve specific evaluation, that is, how to grade student's ability according to students' different reactions and give them personalized comments. To design a complete computer-based problem-solving assessment project, the evaluation mechanism also needs to be considered.

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ABSTRACT

This paper is a collaborative qualitative research project between a Queensland university and a Brisbane secondary school to investigate the use of digital tools for feedback in STEM classrooms. Key research questions include:

How are the digital tools such as OneNote, audio recording and stylus used to provide feedback? What are students’ and teachers’ perceptions of the use of digital tools for feedback? How do teachers and students respond to and utilise the feedback?

Data were gathered in one independent girls’ secondary school (year levels seven to 12) from six semi-structured individual teacher interviews, six groups of student semi-structured interviews (group size two or three students) and six classroom observations of teaching, in which field notes were taken. This data was analysed using thematic coding.

The study revealed that the technology enhanced the high quality teaching and feedback strategies primarily in four ways: first, it reduced the time taken for teachers to give feedback, thus allowing them to communicate with a greater number of students more regularly; second, it allowed teachers to understand each student and to treat each as an individual; third, it improved record-keeping and tracking of student work; and fourth, it made content delivery easier. This work contributes to the knowledge on the effectiveness of using digital tools for formative feedback in STEM learning.

Keywords: Digital, pedagogy, feedback, STEM.

INTRODUCTION

“Feedback is one of the most powerful influences on learning and achievement, but this impact can be either positive or negative” (Hattie & Timperley, 2007, p. 81). This study sought to investigate the effect of incorporating digital technologies into feedback practices in STEM education.

The site for the data gathering was an independent secondary Catholic school for girls, because in addition to focusing on improving staff pedagogical feedback practices for many years, they had recently introduced Surface Pro 3 laptop devices with a stylus, and Class OneNote for cloud storage of teaching and learning materials, student notes and assessment.
These devices afforded enhanced communication options and ways of delivering content and gathering evidence of learning. The study assessed how selected teachers and students used these digital tools in STEM learning, with a focus on formative feedback, and how students responded to and utilised the feedback.

**LITERATURE REVIEW**

There is emerging research on formative assessment using digital tools. One study by Silva (2012) examined student perceptions and attitudes about two different modes and media of teacher feedback; that is, *Microsoft Word* comments versus visual/audio commentary. The findings were interesting with students who preferred the visual/audio modality of teacher commentary videos citing their conversational quality, clarification of expectations and reference to more global issues in writing as important.

Moving away from purely written feedback on assessments to more diverse online feedback genres may enable better reflection by students on their progress. Research has shown that written comments do not guarantee that positive outcomes will occur (Ryan, Henderson, & Phillips, 2016), with high quality feedback being the most important influence on student achievement (Hattie & Timperley, 2007). However, teachers need to be mindful that students’ interpretation of the comments can be inaccurate (Anson, 2015; Thompson & Lee, 2012). Also, face-to-face feedback depends on student recall and may be hindered by performance anxiety (Henderson & Phillips, 2014). Consequently, new tools like the audio recording of comments may allow students the time to re-play, interpret and reflect on the feedback eliminating the need to recall information or misinterpret written comments.

Research has shown that students consider audio recordings to provide more information than text-based feedback, and that audio provides five main strengths; that is, audio is more personalised than text; clarity is increased; it is perceived as more supportive and caring, it prompts reflection; and it is constructive and useful (Henderson & Phillips, 2014, p. 7). Furthermore, students prefer audio-visual recordings to either audio-only or text-only feedback (Marriott & Teoh, 2012) because they can see the teacher’s body language and facial expressions.

The addition of visual cues is useful for students who are familiar with their teacher’s expressions and they may glean more information from intonation, gestures and cues afforded through the audio-visual recording. However, one of the challenges with digitally recorded feedback is that students may feel apprehension at listening to recorded feedback and anticipating negative comments (Henderson & Philips, 2015). Also, some students prefer text-based feedback because listening to a full recording takes time and it is easier to locate specific sections of an assignment when the written feedback is associated with sections of the text (Borup, West, & Thomas, 2015).

Integrated cloud-based technologies where students and teachers can store data on a cloud, has the potential to change teachers’ pedagogical approach beyond the traditional chalk and talk pedagogies (Corvan, Crapnell, & Beckmann, 2017). The cloud enables the extension of connected learning moving beyond the classroom and affords opportunities for students to access feedback outside of class time.

Such strategies enable the building of personal learning environments (PLEs) allowing students to take control of their learning where they can choose the media, sequencing, pacing and content (Corvan et al., 2017). It also affords students greater control over how and when they access feedback and how they contribute to these online communities of learning (Corvan et al., 2017).
The research on the use of digital feedback is emerging showing that it has the potential to change teacher practices and enable rich digitally mediated feedback conversations (Corvan et al., 2017). However, more research is needed on the use of new digital tools that are being used in classrooms such as the stylus and how this influences students’ outcomes and teachers’ pedagogical approaches.

**RESEARCH DESIGN**

Data for this qualitative study were gathered from six semi-structured individual teacher interviews, six groups of student semi-structured interviews (group size two or three students) and six classroom observations of teaching, in which field notes were taken. The observed classes were different STEM subjects and year levels in the secondary school. The purpose of the classroom observations was to see how digital tools were used in feedback practices, and the purpose of the teacher interviews was to discover the teachers’ reasoning and practice around the use of digital tools. The purpose of the student interviews was to discover students’ perceptions of the digital feedback and how they actioned it. The interviews were semi-structured, lasting approximately 50 minutes, and audio recordings were made of all interviews. The interview questions were designed to initiate conversation, with further questions contingent on the answers given. Additional prompts for questions were derived from the classroom observations.

The teachers were selected by the project leaders at the school as being those who were using the technology in different ways. The students were chosen by their teachers based on their ability to talk to researchers with comfort and their availability for interview in their break or lunch time. The students were interviewed in groups of two or three and the session typically lasted 20 minutes. Teachers typically chose students who were a mix of above average and average academic achievers.

The interview data was transcribed and imported into the qualitative research software “NVivo”. This software was not employed to perform automatic coding, but to display and store both the raw and coded data, and to enable the researcher to perform the thematic analysis.

**RESULTS AND DISCUSSION**

The study revealed high quality teaching and feedback strategies, which the research team agreed is likely to gain effective results with or without the use of technology. However, it was evidenced from the analysis of the data that the technology was enhancing the effective pedagogy and feedback, primarily in four ways: first, it reduced the time taken for teachers to give feedback, thus allowing them to individualise and reach more students more regularly; second, it allowed teachers to understand each student and to treat each as an individual; third, it improved record-keeping and tracking of student work; and fourth, it made content delivery easier.

**Feedback practices**

Feedback in the school is conceptualised as a conversation: it is not a one-way delivery from teacher to student, but flows from student to teacher and teacher to student in cycles. OneNote expedites the communication, and provides a record of the conversations and interactions that students can revisit as they develop assessment tasks and reflect on their learning during the year to set new goals for the coming year. One teacher expressed this below:
I think for me OneNote has the ability to facilitate those, what we refer to as digitally mediated conversations, that back and forth between me and them in the collaboration space but then within each of their own individual spaces. (Interview, TeacherCo).

The digital conversation of feedback and questions between the student and teacher is developed as an assessment task evolves, with audio/written comments from the teacher, received by the student via OneNote. Anson (2015) and Thompson and Lee (2012) found that students' interpretation of feedback comments can be inaccurate, so the conversation allows teachers to check that their comments are understood and being actioned. In this case, the audio file is transcribed by the student, forcing her to think about the comments, and she annotates the feedback with further questions. The whole conversation is mediated by OneNote as one teacher recalls below:

I’ll post responses to that either handwritten or typed or audio and then they will listen, and one of my best for that [student name], she will write down everything she’s heard me say in the audio and then next to that she posts questions from the audio that - or from - what she’s listened to and then I can see the question she’s got and then we can extend on that the next time I see her in class. [Student name], you said this, you asked this; the answer to that is that, let’s talk it through. This constant back and forth in which the whole conversation is tracked and then when they go to do their final piece they can see it. (Interview, TeacherCo)

Teachers ask students to justify their reasons for changes to work by recording audio “Snips”:

“Sometimes I have given them written feedback and I have got them to re-write a section and record their justification for their re-writing” (Interview, TeacherE). By doing this, students are forced to carefully consider and understand the reasons for making the changes.

Black and Wiliam (1998) claim that the rapidity of feedback is essential for good learning. Teachers are using the timesaving attributes of OneNote to enable earlier and more frequent feedback to students, and they talked about the changing feedback timescales. OneNote enables teachers to see student work, including drafts and planning at any time, without the need to meet to collect it. This can be seen from these representative comments:

On a Saturday night, I have often sat there and seen girls doing their homework and I will give them feedback as they are producing it (Interview, TeacherE).

They are still from the generation where they got feedback on the draft the week before the assignment was due. We are now getting a lot better at, doing what I did in class today. So, front-ending that’s kind of feedback at the beginning of a unit, so that by the time you get to draft stages, they have already had three pieces of work looked at by another student, or by the teacher. (Interview, TeacherE)

OneNote has allowed the teacher to see each student’s work on a more frequent basis, since it has removed the need to meet to collect and re-distribute. This has allowed teachers to identify conceptually difficult areas, and be able to plan what content to revisit in the next face-to-face teaching situations. Teachers report that they are “seeing problems as they arise” (Interview, TeacherN).
Black and William (1998) also talk about the importance for students to not be passive recipients of feedback. Teachers are encouraging students to write questions for the teacher. The students need to identify the gap between their present understanding and the desired goal (Black & Wiliam, 1998), and the study found that some teachers intentionally developed students’ self-efficacy by encouraging them to identify the areas of learning with which they were struggling.

Black and Wiliam (1998) write that the role of students in assessment is important, especially when they engaged in self and peer assessment. OneNote enables easy sharing of resources, and working in the online class collaborative space. Students can edit the same work simultaneously, seeing one another’s contributions appear in real time. Teachers are using the collaborative space to develop higher order thinking, asking the girls to critique one another’s work and developing strategies for constructive feedback. One teacher explained how he gave the students some guidance to enable this to occur:

I already had inside my collaborative space a set of parameters I wanted them to work in. “When you do this, I want you to think about the strength of this person’s argument, the strength of the sources, what kind of evidence or examples are they producing to support that, what positive critique can you offer, constructive feedback?” (Interview, TeacherCo)

CONCLUSION

It was seen that digital tools such as OneNote were used predominantly to mediate a digital conversation between staff and students to develop learning. Staff have been intentionally developing their feedback strategies during the last few years and the results of this study showed many practices that align with effective feedback as reported in the literature. For example, students are active participants in the feedback process engaging in quality dialogue where possible (Graesser, Person, & Magliano, 1995). Furthermore, the feedback from teachers focusses on areas of improvement linked to progress rather than comparisons between students (Schunk & Rice, 1991; Schunk & Swartz, 1993), and a focus on improving quality rather than just grades.

It was found that feedback is conceptualised as a conversation: it is not a one way from teacher to student but flows from student to teacher and teacher to student in cycles. Teachers might record audio comments when reading a draft. These comments might elicit questions from students via audio clips, and further clarification from teachers. Students might then action the changes and record audio clips to justify their reasoning behind the changes they made.

Many effective feedback strategies were being used by teachers, which were enabled by OneNote. OneNote enables the rapid delivery of feedback, since teachers are able to see student work as it is created and they are not dependent upon physical meetings in class time to collect work before being able to read it and give feedback. The easy access to and sharing of pages in OneNote enables peer feedback to be conducted, either in class or for homework. The literature shows that rapid and timely feedback is necessary for success (Black & William, 1998).

Teachers have been intentionally developing feedback practices that require students to assimilate the feedback. Using audio recording allows students to play back and repeat parts they were unsure about, or had forgotten since a face-to-face conversation. Teachers require students to incorporate this feedback into their work, and OneNote affords them opportunities to monitor that this has been done by every student. Some teachers have asked students to
create small audio files that summarise their changes based on the feedback, and their reasons for implementing these changes, which forces students to reflect on their learning. Students are very motivated to improve academically and value feedback as a means to help them achieve this.

Whilst this is a qualitative study using a single case, this study identified examples of highly successful utilization of digital technologies that enhanced and modified existing strong feedback pedagogies and contributed to STEM learning. These findings could inform pedagogy in other similarly digitally-rich learning environments.

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ABSTRACT
Teaching and designing for STEM and STEAM education can be enhanced through the establishment of connections with experts outside regular teaching and school staff. This is particularly important in the multi-age classroom as this expertise can support the teachers and the learners. In this novel study, we apply a design framework to understand the way in which different combinations of experts (school staff, engineers, as well as education technology and arts education academics) contributed to a STEAM unit of work enacted in a multi-age classroom. We draw on data from the teaching Principal’s reflections, design artefacts and samples of student work to describe the importance of: explicit conceptualizations of assumptions about teaching and learning as well as flexibility in roles including leadership. We conclude with recommendations regarding the design of assessment for STEAM units of work, particularly regarding the assessment of language development, as well as communication with other stakeholders.

Keywords: STEAM education, Multi-age teaching, PBL, Design for Learning

INTRODUCTION
Complex learning environments are those that require the combination of tools, social interactions and ways of knowing to achieve a particular goal (Goodyear & Carvalho, 2013). Careful design of such learning environments, and the tasks undertaken within them, is needed to ensure that opportunities for learning are provided for all students. A collaborative approach to design and teaching can be used in situations that include additional complexity, such as those that involve multi-age classes (with significantly different expectations of learners) or STEM/STEAM units of work (with multi/inter/transdisciplinary approaches to knowledge and ways of knowing) (Herro & Quigley, 2017; Thompson et al., 2017).

In this novel study, we describe the process of co-design and co-teaching of a STEM/STEAM unit of work in a P-6 multi-age class. We apply the Activity Centred Analysis and Design (ACAD) framework (Carvalho & Goodyear, 2014) to guide the analysis of the key design elements and processes. Drawing on design artefacts, the teaching Principal’s reflections, and samples of student work, we identify productive aspects of the design, and challenges in implementing this approach.

LITERATURE REVIEW
Science, Technology, Engineering and Mathematics (STEM) education has been declared a priority internationally (Land, 2013) as well as nationally (Education Council, 2015). STEAM education adds the Arts to facilitate the connections between disciplines, creativity, problem solving, innovation, and curiosity (Hetland, Winner, Veenema, &
Sheridan, 2007). Whether discussing STEM or STEAM education, this integrated approach can encourage project-based learning, inquiry, and inter/transdisciplinary approaches to understanding complex problems (Connor, Karmokar, & Whittington, 2015; Herro & Quigley, 2017). While the literature discussed in what follows addresses STEAM education specifically, it is the interconnected, interdisciplinary aspect of the teaching and learning that is key and equally applicable to approaches to STEM education.

Daugherty (2013) states that the separation of the Arts from STEM subjects was acknowledged nearly six decades ago by Snow (1959) who observed that there was no justifiable academic basis for the lack of communication which arose between these discipline areas. Blackley & Howell (2015) contend that ‘silos’ of learning based on discrete disciplines where tertiary, school and community sectors are separated, have produced single discipline understandings of complex issues, oversimplifying human-environment relationships.

STEAM education can provide teachers with an opportunity to collaboratively learn as well as teach with interdisciplinarity (Wynn & Harris, 2012). By using creativity and imagination to address interesting and important subjects, STEAM can stimulate and inspire students to engage and interact with learning. Introducing students to the concept of “decentralized leadership” (p.43), as in a jazz model of performance, can assist in preparing them for the workplace.

Much of STEAM education is carried out in the form of problem-based and project-based learning which involves small groups. While not specifically referring to STEAM contexts, Blumenfeld et al. (1991) discuss the value of this strategy and their explanation of the requirements of group work aligns closely with a STEAM approach to learning. These include: basing student communication on reasoned and higher order thinking; ensuring cognitive processing includes rehearsing, organising and integrating information; and acknowledging respect for their participants’ ideas and perspectives.

Essential components of problem-based learning include: that a question or problem is required to organise or drive activities, and that these activities produce a series of artefacts or products that culminate in a final product which addresses the driving question (Blumenfeld et al., 1991). These authors observe that project-based learning provides a framework in which, “students pursue solutions to nontrivial problems by asking and refining questions, debating ideas, making predictions, designing plans and/or experiments, collecting and analysing data, drawing conclusions, communicating their ideas and findings to others, asking new questions, and creating artefacts” (Blumenfeld et al., 1991 p. 371). They explain that, “learners construct knowledge by solving complex problems in situations in which they use cognitive tools, multiple sources of information, and other individuals as resources” (Blumenfeld et al., 1991 p. 371).

Collaborative approaches to design (Thompson & Kanasa, 2016) and teaching (Hobson & Malderez, 2013) are not new. They can involve mentoring relationships (Kelly & Antonio, 2016) or involve stakeholders beyond usual school teaching staff (Thompson et al., 2017). Inter/transdisciplinary are terms often applied to approaches to team science (Pennington et al., 2016) rather than education (Herro & Quigley, 2017; Thompson et al., 2018), however their definitions lend themselves to describing collaborative approaches to STEAM education.

Interdisciplinary refers to those situations that are synergistic across disciplinary perspectives within the same context (e.g. school teachers co-designing a unit of work), with each discipline drawing on concepts from others while remaining identifiable (Pennington et
Transdisciplinary can refer to discipline spanning concepts or activities that include professionals and stakeholders from different contexts (e.g. school teachers co-designing a unit of work with stakeholders such as university academics) (Pennington et al., 2016).

Team teaching has been suggested as advantageous in terms of expertise and feedback (Buckley, 2000). Sarason (1966) identified that even though teaching staff are involved in working beside others they have limited opportunity to reflect upon their work in collaborative manner. One challenge identified in the research on interdisciplinary approaches to educational design is the difficulty in connecting knowledge across disciplinary boundaries in the way necessary for team members to combine their unique knowledge and skills (Thompson et al., 2018). Herro and Quigley (2017) identified that there is very little research which exists about the development and implementation between teachers in the development of a STEAM unit.

Multi-age classroom contexts provide additional complexity, with teachers accommodating significantly different expectations of learners, their activity, and learning outcomes. When drawing on a constructivist underpinning (Piaget, 1973), multi-age classrooms can accommodate active, creative approaches to learning and teaching (Kalaoja & Pietarinen, 2009). The aim for these classrooms is that they are child-centred, collaborative and flexible, whilst promoting social and academic attributes (Dewey, 1902; Robinson, 2010). The typical multi-age class may consist of two or more age groups with one classroom teacher which, in most cases can be found in small rural schools.

METHODS

This project involved a multi-age primary school in metropolitan Brisbane, with thirty students, one teaching Principal, and one other teacher. The school was established based on a commitment to the multi-age concept. Over the past two years, school staff have undertaken to re-define the concept of multi-age as well as forming partnerships with a university. The school has decided that STEAM education will be a major curriculum initiative.

University staff specialising in engineering, technologies education, and arts education were asked to be part of the design and teaching teams. An initial meeting with the design team was held, and regular meetings between the co-authors were held to reflect on the progress of students and to make any changes to the design of the following week’s lesson. Teaching staff engaged in informal reflections at the end of each class (typically three hours, once a week).

The goal was for the group of thirty students to engage in a term-long STEAM project, with most of the work to be carried out on university grounds. The STEAM unit involved students engaged in the design, construction, and decoration of a box (engineering, mathematics, visual art) that was then used to store a robot (Beebot or Lego Mindstorms) that was programmed to move along a grid (Technologies).

Students recorded their activity using video and photos (ICT as a general capability), wrote or recorded reflections (literacy), and presented their work to parents and other interested community members at the end of the term. The box and robot activities took place at Griffith University’s Creative Practice Lab (see Figure 1).
The Creative Practice Lab (Figure 1) is a purposefully designed space for preservice teacher education and researching creative educational practice. Participants have access to a range of tools (digital and physical), and the space is equipped with multiple video cameras and audio recorders. Multiple streams of data are able to be collected, processed, and analysed, combining video, audio and image files.

The Activity Centred Analysis and Design (ACAD) framework was used in this study (Carvalho & Goodyear, 2014). Inspired by accounts of situated learning, the ACAD framework supports researchers in making connections between learning activity and the designed environment. The ACAD framework focuses on the elements of any learning environment that are able to be designed: the epistemic design (the task), the social design (the rules, and roles), and the set design (tools and resources both physical and digital).

This supports researchers to explore how observable learner activity is connected to underlying design intentions, which in turn, influence learning outcomes. In this paper we draw on the teaching Principal’s reflections, design artefacts, and samples of student work to describe: the underlying assumptions of learning and teaching in a multi-age class and present the framework that informed the teaching Principal’s perspectives; the social (roles of teaching staff, connections between students and teaching staff), and the epistemic (student engagement in the task, assessment).

FINDINGS

The teaching Principal (and first author) identified the conceptual pedagogical framework to account for the multiple theories that intersected and informed his classroom practice within this multi-age environment (Figure 2).
The framework provides structure drawn from research that assisted this teaching Principal in pedagogical decision-making during the design as well as teaching phases. Drawing on the teaching Principal’s reflections, the design of the unit was informed by: the conceptualisation of a multi-age framework; the need to integrate and connect subjects where possible; the importance of responding to students’ input; flexibility in design and teaching team roles; and frequent reflection on the ultimate aim of the unit.

The social design was particularly important in terms of the teaching and design teams. The teaching team consisted of the teaching staff from the school and university staff including experts in engineering, technologies and arts education. The ultimate design of the unit is presented in Figure 3 below.

**Figure 2. A multi-age pedagogical framework**

**Figure 3. Design of the STEAM unit**

The leadership roles were flexible depending on the tasks students were required to complete. In one class, the engineer led the students in the design of their box, the
Technologies expert connected this work to the design cycle, and teaching staff made connections with regular classroom practices involving collaboration and problem-solving. All members of the teaching team helped students. It was necessary for the team members to meet on regular basis in order to discuss the process of the students and adapt the next session in order to meet the planned timetable.

Student engagement with the tasks, classmates, and the teaching team were considered important. A healthy social environment between any classroom teacher, the student, and their class mates has been linked to improved academic and social opportunities (Mc Garth & Noble, 2003; Topping, Peter, Stephen, & Whale, 2004). The STEAM unit was complex, students ranged in age from 6 to 12, and not all members of the teaching team were school teachers.

The teaching Principal’s reflections noted that attendance data was consistently above the average of 94%, which could indicate that students were enthusiastic about the STEAM unit. The reflections also noted that younger students (to year 2) were willing to problem-solve in groups, and that older students were persistent in problem-solving activities. In particular, students with special needs were included by older students, and their strengths were used to help problem-solve. The students were engaged with the teaching team, asking questions and valuing the expertise available.

The aspects of the epistemic design that the researchers focused their attention on was the development of appropriate language by the students. This was important for successful participation in the STEAM unit. The teaching Principal noted that there was an observable difference in the oral and written scientific language of the students. The senior students produced a diary over the term and presented this to parents and other community members. Diary entries showed that some older students had limited vocabulary to describe their activity (Figure 4).

Figure 4. Sample of senior student work

In meetings between the researcher and the teaching-Principal the limited language was discussed, and it was decided that the development of language should be linked to the assessment in future iterations. In this unit, was based upon a self-assessment with observations from the teaching team. The parental feedback about this unit was positive and the parent community advocated for further assessments to feature student involvement, demonstrations and, where appropriate, student oral feedback. Quigley, Herro and Jamil (2017) have noted the need for further research in the determination and validation of
assessment tools that provide a better picture of what students are achieving in STEAM education.

CONCLUSION

The multi-age classroom is a complex learning environment in which the introduction of project-based learning, with a collaborative approach to design and teaching needs careful planning. In this case, the teacher Principal’s pedagogical decision-making was supported by an explicit conceptual framework. Reflective practice by members of the teaching and design teams were guided by this, and the needs of each of the students remained core to all decisions.

The design of the assessment was informed by all members of the team, however further research is needed into the connection between the conceptual framework, the alignment of the STEAM units and the appropriate measurement tools. It is through the validation of these assessment tools that we can identify whether STEAM is having the desired influence upon the students and their learning. Our ultimate goal is to engage with the learner, and to prepare and implement curriculum programs for students who then become better equipped to handle future challenges.

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ABSTRACT

Speaking ability is a critical aspect of STEM education. However, the ability to train students in oral expression is single, and their interest is low, which does not achieve the expected teaching effect. To solve this problem, this study uses a mixed research method to analyse the change of learners' oral expression in the STEM classroom where Scratch is applied. We collected the classroom observation data of eight STEM courses for the second-grade Chinese students and conducted qualitative analysis of students' speaking discourse. These studies reveal that the application of Scratch and picture book teaching aids in STEM classrooms can help students improve their oral expression ability. The results also indicate that by creating picture stories with Scratch, students' speaking ability has been improved in terms of "speech complexity," "content fluency" and "emotion involvement". The follow-up interview also shows that the students' interest in oral expression has been promoted. Pedagogical implications and future research are discussed at the end of this paper.

Keywords: STEM education, Scratch, classroom teaching, oral expression

INTRODUCTION

STEM education integrates teaching methods, focusing on practice and process, emphasising knowledge and ability. Oral expression ability is an important part of STEM education. In class, it is an important goal of primary school teaching to train students' oral expression ability and improve their active learning interest (Schneider, & Hayward, 2010).

The traditional teachers teaching and students learning classroom is faced with the following problems in cultivating students' oral expression ability: first, elementary school students' logical thinking ability is weak, oral expression needs the support of specific content; Second, the students' interest in oral expression is not high; third, a lack of expression practice of their own personal and reading experience results in students' speech expression not being in place, and other problems (Wu, 2014).

In order to solve the above problems, this study innovatively changes the traditional way of cultivating students' oral expression ability in the interdisciplinary, practical and interesting STEM classroom, combine the easy-to-operate, situational Scratch and interesting picture book stories, to solve the problems of students' weak logical thinking ability, low interest in oral expression and poor understanding of oral expression materials, so as to effectively improve the students' oral expression ability.
LITERATURE REVIEW

STEM Education

STEM Education is a shorthand for Science, Technology, Engineering and Mathematics. It is not the process of teaching and learning the knowledge of four subjects simply superimposed, but emphasises the natural combination of the contents of the four scattered subjects to form a whole learning project (Morrison, 2005). STEM education is a kind of "creation-based learning", in the process of integrating STEM education, it mainly adopts the methods of project-based learning and inquiry learning, and sets up the mutual interaction consciousness of different knowledge among different subjects (Yu, 2015).

In the STEM classroom, learners explore and understand the different aspects of a scientific and objective phenomenon, and in the real classroom learning to improve scientific literacy, technical literacy, engineering literacy and mathematics literacy. STEM education develops students' knowledge and skills through integrated teaching methods, and can be applied to solve real-world problems through flexible migration (Zhao, 2012). STEM education is a systematic educational means to help learners to learn interdisciplinary knowledge and understand the objective world, it is also a direct way to cultivate students' comprehensive ability.

Research on Scratch

Scratch is more suitable for primary and secondary school students to learn program knowledge, stimulate students' motivation and interest in learning, and ultimately can improve the ability of students' logical thinking, problem solving and group cooperation (Yuan, 2014).

According to the characteristics of Scratch, from the perspective of pedagogical theory and methods to analyse, Scratch mainly includes story elements, action elements, problem elements, creative elements and sharing elements. Ouahbi study shows that by making Scratch game to learn the programming language, the students’ learning results are better, and the students have shown strong interest in learning (Ouahbi & Kaddari, 2015).

The Scratch is introduced into the teaching to cultivate the students' ability of solving problems independently and the ability of group cooperation in the process of practical operation, and to arouse the students' innovative consciousness (Cheng, 2014). On the one hand, researchers study the application of Scratch in different disciplines, on the other hand, they explore and summarise a relatively reasonable teaching model.

Research on picture books

Picture books that children came into contact with in the enlightenment stage and in the earliest period of their life. It is deeply loved by the readers of children. For the definition of picture books, experts and scholars agree that picture books are combination of painting and language, suitable for younger children to read. (Yao, 2011).

According to the characteristics of picture books and from the perspective of pedagogy theory and method to analyse, picture books mainly include story elements, creative elements and sharing elements (Luo, 2009). Nowadays, picture books have great possibilities in developing students' multiple intelligence, enhancing their imagination and expressiveness, and so on (Lu, 2016). The picture books mainly takes the picture as the main body, the text is less, and most of them express the story plot with the picture, it can stimulate students' interest in reading and learning more than plain text.

To sum up, in order to change the teaching method of cultivating students' oral expression ability in the traditional class, this study innovatively combines Scratch with
picture books, and combines the characteristics of STEM classroom with the characteristics of students' physical and mental development, and constructs a teaching framework for the improvement of students' oral expression ability to solve the problem of students' weak language expression ability.

RESEARCH DESIGN

Methods
In order to solve the problem, we conducted an eight-week course and conducted classroom observation. The teaching object is 28 students of grade two, the interval of each teaching activity was one week, each time was 2 hours.

At the beginning of the formal activities and after the structured activities, researchers carried on a test on the students' oral expression level using the selected speech test questions. In the experiment, each student was presented with a speech test separately. After reading the picture, the students prepared it for one minute and then spoke. In the process of speaking, the researcher made a recording. Pretest and posttest data are shown below:

![Figure 1. Pretest oral expression story](image1)

![Figure 2. Posttest oral expression story](image2)

Teaching process
STEM course is an experiential course to guide students to use interdisciplinary knowledge, cooperate, design, construct, discover and solve problems in the way of project activities. In the course of STEM, using scratch and picture books, the course is designed scientifically by means of interdisciplinary integration and learning scaffolding, so as to provide students with the classroom environment of "learning by doing", and to combine Scratch with picture books to construct the framework of STEM curriculum. This framework contains five teaching processes: select the theme, determine the target, utilise resources, designing the process, and conduct evaluation.

The framework takes Scratch and picture books elements as the core, and combines the characteristics of STEM education. Through understanding picture book stories, students use Scratch to make their own story to express the story plot, and they learn to analyse problems, create stories, and communicate in practical operation. The teacher integrates two picture book stories to let students describe the scene and test their oral expression ability.

Teachers use Scratch to guide students to run case program, clearly specifying the theme of creation; The students need to design their story content, display their imagination on the basic elements of animation, such as characters, scenes, sound and so on, complete the Scratch animation production, and describe the story; Combining the characteristics of picture books with the Scratch program, students fill out the corresponding program instructions according to similar stories, and finally form a complete story. Teachers ask
students to express their stories and exercise their "language complexity", so that students can complete the narration of the stories in the process of communication and sharing.

At the end of the course, the researchers used the method of content analysis to analyse the students' pretests and posttests results from three aspects: "speech complexity", "content fluency" and "emotion involvement". At the same time, the story script was analysed qualitatively, and all the students were interviewed.

RESULTS

In order to compare the specific changes of the oral expression ability of the students in pretests and posttests, we analysed the data of the oral expression of five students. The results are shown in Table 1 as follows:

<table>
<thead>
<tr>
<th>Student</th>
<th>Word number variation</th>
<th>Meaning unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre tests</td>
<td>Post tests</td>
</tr>
<tr>
<td>A</td>
<td>49</td>
<td>61</td>
</tr>
<tr>
<td>B</td>
<td>40</td>
<td>85</td>
</tr>
<tr>
<td>C</td>
<td>41</td>
<td>99</td>
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<tr>
<td>D</td>
<td>64</td>
<td>113</td>
</tr>
<tr>
<td>E</td>
<td>30</td>
<td>94</td>
</tr>
<tr>
<td>Mean value</td>
<td>44.8</td>
<td>90.4</td>
</tr>
</tbody>
</table>

The results showed there were significant differences between pretests and posttests of the students’ oral expression in the two statistical values of word number and meaning unit. It shows that after classroom teaching training, students' oral expression ability has been improved.

Here, five students' spoken language expression ability script as the qualitative analysis material, in order to better display the students' oral expression situation in the pretests and posttests, as shown in Table 2 below:

<table>
<thead>
<tr>
<th>Students</th>
<th>Pre tests</th>
<th>Post tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The first picture, there was a rabbit plowing, and she was growing a vegetable field. In the second picture she was planting seeds, she wanted to plant a field. The third picture she had planted a little bit. In fourth picture she is</td>
<td>One day there was a little monkey who wanted to plant a tree, so he dug the earth, dug a deep mud pit, and planted a tree seed in it. So every day, he is happy to water it, plant seeds, and soon it will grow a bit of small flowers, and then, it has become little peaches bit by bit.</td>
</tr>
<tr>
<td></td>
<td>finished, she had planted white vegetables.</td>
<td>There was a monkey who wanted a big tree. But the tree is smaller with the time went by, it was watered and fertilised. Why? Because he poured too much water and applied fertilizer, he reduced it a little bit. In the end, he grew some flowers, and finally he grew some peaches. The little monkey picked all the peaches, he used these as winter food, and finally had the food to hibernate in the winter, so that the little monkey would no longer starve.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>B</td>
<td>The first means that there is a rabbit, she wants to plant a field, the second picture is plant a seed, the third picture she watering every day, the fourth picture the vegetables are ripe, and she can eat them.</td>
<td>Throughout the story, the little monkey was very happy, he hoped that the peach would grow quickly, and that after a while, the peach had really grown. The little monkey happily picked the peach and went home to eat.</td>
</tr>
<tr>
<td>C</td>
<td>The rabbit is digging the earth, in the evening he began to sow seeds, the next morning the seedlings grew out, the rabbit was watering, and finally the food grew again in the evening, the rabbit happily pulled the vegetables home.</td>
<td>There was a little monkey planting trees. It was a hot summer, but he was still planting trees. He was watering them now, the next night, the tree had grown up, and he began to fertilize it, it suddenly occurred to him what a tree it was. The next morning he will know, it was the next night, and the next morning he came in front of this tree, and he saw that there were some pale pink flowers in the tree, and at night there were several peaches on the tree, and the little monkey was very happy.</td>
</tr>
<tr>
<td>D</td>
<td>There was a little rabbit, she found it particularly difficult to buy food outside, so she decided to plant at home, she began to dig the soil, after digging, she began to sow. The little rabbit took the kettle and watered them, and at the end the seedlings grew into vegetables, and the rabbit could pick them up and take them home to eat.</td>
<td>One day the little monkey planted a peach tree, one more day, the next day he came to water the sapling, and the next night he came to the tree and found that it had become a bigger tree, on the third day, the little monkey came to the tree, he found that the peach tree had blossomed, and on the fourth night, the little monkey came to the tree and found that the peach tree had grown fresh and tender peaches, so he picked some peaches and prepared to go home to eat.</td>
</tr>
<tr>
<td>E</td>
<td>A rabbit was plowing one day and sowing seeds at night. After a few weeks, she found that some vegetables were growing in the garden, and she took them home.</td>
<td>There was a monkey who especially likes eating peaches, and he found it particularly inconvenient to buy them in the market, he planted a peach tree in his own house and watered his sapling every day, one night, he found that his peach sapling had grown into a tree, so he took a bag of fertilizer to fertilize it, and on one mornings after a few days, he found that the peach tree had blossomed and the monkey was very happy. He hoped that the peach would grow quickly, and that after a while, the peach had really grown. The little monkey happily picked the peach and went home to eat.</td>
</tr>
</tbody>
</table>
The results showed that after comparison between pretests and posttests the students have significantly improved in the three indicators of "speech complexity", "content fluency" and "emotion involvement". It showed that the application of Scratch and picture book teaching in STEM classroom can improve the students' oral expression ability.

In the later tests of language expression ability, the complexity of using words by students is increased, the language is more vivid and the story elements (time, place, process and result) are more complete, and the expression is more natural and emotional. The stories told by students in class are richer and more vivid, mainly reflected in the longer length of story paragraphs, the more number of meaning units, the more diverse verbs and conjunctions.

In addition, after the course we conducted interviews with the students, in terms of the love of the course, all the students said that the course is very interesting, and they like to use Scratch to tell story in the animation process. They think the interactive stories that made by themselves, because animated characters can move, and they're familiar with the protagonists, the background, the events, they can tell the story without having to think too much about it, and they don't have to worry about being wrong, and the story is more vivid; and said that there is more thinking about the description of the action by making animation firstly and telling the story lately.

DISCUSSION AND CONCLUSIONS

This study combines Scratch with picture book to develop creative teaching practice based on making picture book animation for primary school students. The results show that scratch and picture book can improve students' oral expression ability. At the same time, through the analysis of the practical significance of this study, put forward to the suggestions of combination the scratch and STEM education in the future, and training students' comprehensive ability.

In STEM class, the process of making picture book stories with Scratch as a tool is the process of students expressing emotion and arousing students' language expression ability, in teaching practice, digital support can be added to STEM classroom, so as to optimise the effect of teaching, stimulate students' interest in learning, play a subjective initiative, through cooperation, exploration, thinking training and other ways to cultivate the comprehensive ability of oral expression.

Although there are still many difficulties and challenges in the implementation of STEM education, with the strategic development of educational informatization, on the basis of the existing teaching mode and teaching experience, combining with the development characteristics of STEM education itself, reasonable use of teaching aids to design and develop a series of educational activities to enable the comprehensive development of STEM education.

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REFERENCES


THE EFFECT OF GRAPHICAL AND TEXTUAL PROGRAMMING WITH MICROBIT ON MIDDLE SCHOOL STUDENT'S CT SKILLS

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ABSTRACT

Programming is an essential approach to increase computer thinking. In recent years, graphical programming and hardware-based programming are frequently used in programming education. To determine whether graphical programming and textual programming with micro:bit (a programmable microcomputer) can improve student’s computational thinking (CT) skills, we tested 39 middle school students, who were allocated to intervention and control groups. In the control group students were taught python in a textual programming environment for 16 class hours. In the intervention group, students were taught in a graphical programming environment. Both of the groups used the same hardware, micro:bit. Two independent-sample T tests and a Paired-samples T test were conducted. Results revealed that, while both groups showed significant effects, graphical programming with micro:bit can better improve student’s CT skills. What’s more, graphical programming environment can help students in completing more complex programming work, which means that graphical programming is more suitable for comprehensive and problem-solving programming learning tasks.

Keywords: Computer thinking; graphical programming; textual programming; micro:bit

INTRODUCTION

Computational thinking (CT) can be defined as a problem solving process and a way of thinking in which patterns are produced with technological tools to solve problems (Aho, 2012; ISTE,2016; Wing,2011; Saritepeci & Yildiz-Durak, 2017). There is a general acceptance that CT skills cover the concepts of “abstraction, algorithmic thinking, problem-solving, decomposition, generalisation, and debugging” (Durak & Saritepeci, 2017). CT represents applicable attitude and skill set for everyone, and it provides advantages in learning and teaching process and daily life (Saritepeci & Yildiz-Durak, 2017; Wing, 2006). Embedding CT skills in the K-12 and University curricula is necessary for training the next generation of thinkers (Boechler, Artym, Dejong, Carbonaro, & Stroulia, 2014).

There is a broad consensus that programming education and production based technology activities which are especially based on programming instruction promote the improvement of computational thinking skills (Boechler et al., 2014; Durak & Saritepeci, 2017; Lee, Apone, & Apone, 2014; Lye & Koh, 2014). Robotic coding, along with the increased popularity of robotic kits, is getting more common in schools across all levels of K-12, from kindergarten to high school (Rogers, Wendell, & Foster, 2010; Saritepeci & Yildiz-Durak, 2017). In related works, researchers found that students expressed more positive emotions while programming with robotics (Merkouris & Chorianopoulos, 2015). Block-based commands can reduce the cognitive load on the students and allow them to focus on
the logic and structures involved in programming. For this case, there are approaches that prefer graphical programming languages, rather than traditional programming languages, to facilitate the dimensions of computational thinking (such as concepts, practices and perspectives) specially in K-12 contexts (Bau, Gray, Kelleher, Sheldon, & Turbak, 2017; García-Peñalvo & Mendes, 2017). Saritepeci suggests that block and robotic coding provides a more flexible learning process that promotes learners’ creativity and eliminates the limitations in robotic kits (Saritepeci & Yildiz-Durak, 2017).

However, research into evidence of hardware-based graphical programming that enhance the CT skills is not as extensive. In this paper, an empirical study was conducted to explore the effects of graphical programming and textual programming on CT skills in a hardware-based environment.

LITERATURE REVIEW

CT was generally interpreted as a collection of capabilities which includes creative, logical thinking, abstraction, algorithmic thinking, problem-solving, decomposition, generalisation, debugging, etc (ISTE, 2016; Durak & Saritepeci, 2017). Numerous researches have indicated that CT was highly correlated with the abilities mentioned in the Twenty-First Century Skills such as being able to communicate, share, and use information to solve complex problems, being able to adapt and innovate in response to new demands and changing circumstances, and being able to marshal and expand the power of technology to create new knowledge (Wing, 2011; Binkley et al., 2012; Saritepeci & Yildiz-Durak, 2017).

Based on this, there is a worldwide trend of developing students' CT skills and using CT in interdisciplinary teaching. For example, in 2014 England formally incorporated the study of CT and computer programming into the curriculum of primary and secondary education (Department for Education England [DfEE], 2013; Basogain, Olabe, Olabe, & Lugo, 2017). The United States conducted pre-university students to participate in CT activities by the Advanced Placement Computer Science courses (Dan, Harvey, & Barnes, 2015; Basogain et al., 2017). A lot of researches has been carried out from different aspects to measure and promote student’s CT skills. Several studies explored the learning strategies such as project-based learning for supporting programming learning (Basogain et al., 2017; Chen et al., 2017; Marcelino, Pessoa, Vieira, Salvador, & Mendes, 2017).

Although the importance of programming education for CT is well realised, empirical research into the effect of computer programming on computer thinking is not sufficient. Lye and Koh (2014) investigated researches in the development of Computational Thinking through programming but found they were conceptual papers, literature reviews, or empirical studies where programming was not used to foster computational thinking. For example, Denner, Werner, & Ortiz, (2012) analysed three key competencies of students when programming a game, and these competencies were thought important for engaging children in computational thinking.

From the literature we can find that graphical programming environment is used frequently because of its easy-to-implement structure and algorithm of the programs (Topalli & Cagiltay, 2018). Werner, Denner, Campe, and Kawamoto (2012) conducted a study of how game creation and pair programming can promote middle school student’ CT performance which was conducted in computer game programming classes held after school and during electives.

In this study, researchers created the Fairy Assessment as an Alice program to analyse two of the three parts of CT identified by the Carnegie Mellon Center for Computational
Thinking (CMCCT). However, the analysis is not persuasive enough. One limitation is the lack of a test of construct validity whether the Fairy Assessment really measures the aspects of CT. Another limitation is that the article did not clarify which variable actually affects Computational Thinking skills.

Hardware-based programming such as educational robotics (ER) and Arduino comes into the classroom along with graphical programming. Hardware-based programming requires higher programming thinking and logical thinking than traditional programming. As a result, it may place heavier learning burdens on students. There is a lack of empirical research on how to develop hardware-based programming education to promote students’ CT skills.

Saritepeci and Yildiz-Durak (2017) analysed the effects of the computational thinking skills on high school students in generating solutions to problems with block and robotic coding activities. The study used the “Computational Thinking Ability Scale” which consists of five factors (Creativity, Algorithmic Thinking, Collaboration, Critical Thinking, Problem Solving). However, the study didn’t incorporate the traditional programming environment as a variable into consideration.

The current study attempts to carry out hardware-based programming education for middle school students to compare the difference between graphical and textual programming for CT promotion. Research questions are as follows:

1. Can hardware-based programming education improve students' CT skills?
2. Whether the graphical programming tool can better improve CT skills than textual programming?

RESEARCH DESIGN

Participants

Participants were 39 students from four middle schools of China, included 76.92% (N=30) female and 23.08% (N = 9) male. The average students age is 13 years old. All students were enrolled in a course titled “Creative Electronic Programming”, the purpose of which was to introduce how to design a creative programming works using python.

Because the trial was conducted through a two-day voluntary registration course, we selected students who participated in the entire learning process. This resulted 18 sample points (students) in the intervention group and 21 sample points in the control group. All the participants could operate computers skilfully with no Arduino studying experience.

Data

In this study, researchers created a computer thinking quiz (A&B) as measuring tools for the Pre-post test. All the questions in the quiz were selected from the International Challenge on Informatics and Computational Thinking (Bebras) from 2014 to 2016. So the reliability and validity is good. These question questions cover five dimensions about CT thinking.

Each test paper includes six problems and each problem consist of two or more factors of CT skills. It is thinking, abstract thinking, decomposition algorithm thinking, assessment and generalisation. The two sets of papers are quite difficult and the difficulty is appropriate. The total score is 100.

For the final product, Lin’s evaluation scale of scientific and technological works are adapted (Lin, 2011) to evaluate students learning performance. The scale is divided into five
dimensions (novelty, logicality, robustness, integrity, and complexity). There are 4 points in each dimension; 1 is poor, 2 is normal, 3 is good, and 4 is excellent (full marks). The scale is given in Table 1

**Procedure**

The pre-test was administered onsite through a 30-minute paper test. This diagnostic test was conducted directly before the teacher began his teaching program. Following the pre-test, the students participated in the learning task—a 16-class hours programming course with micro:bit. The research procedure lasted for two days, and both groups were taught by the same teacher using task-driven teaching strategy.

The learning tasks were quite difficult, and they covered programming thought and electronic sensor knowledge. The difference was that the experimental group used the graphical programming tool, Mixly, while the control group used the textual programming tool, python.

At the end of the courses, the two groups of students chose a subject and wrote a program to complete a creative electronic work in 60 minutes using micro:bit. Two professional teachers graded based on the evaluation form of the science and technology works. After the course was completed, all students participated in a 30-minute post-test.

<table>
<thead>
<tr>
<th>Items</th>
<th>Description</th>
<th>Specify</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novelty</td>
<td>Originality of work design</td>
<td>4 (excellent) The work is very creative;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 (good) The work has good ideas;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 (normal) The work creativity is mediocre;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 (poor) The work creativity is extremely poor.</td>
</tr>
<tr>
<td>Logicality</td>
<td>The integrity of the work logic</td>
<td>4 (excellent) The integrity of the work logic is excellent;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 (good) The integrity of the work logic is good;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 (normal) The integrity of the work logic is general;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 (poor) The integrity of the work logic is extremely poor.</td>
</tr>
<tr>
<td>Robustness</td>
<td>The strength of the design</td>
<td>4 (excellent) The robustness of the work is excellent;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 (good) The robustness of the work is good;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 (normal) The robustness of the work is general;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 (poor) The robustness of the work is extremely poor.</td>
</tr>
<tr>
<td>Integrity</td>
<td>The integrity of the work code</td>
<td>4 (excellent) The integrity of work code is excellent;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 (good) The integrity of work code is good;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 (normal) The integrity of work code is general;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 (poor) The integrity of work code is extremely poor.</td>
</tr>
<tr>
<td>Complexity</td>
<td>The complexity of the work</td>
<td>4 (excellent) The complexity of the work is excellent;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 (good) The complexity of the work is good;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 (normal) The complexity of the work is general;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 (poor) The complexity of the work is extremely poor.</td>
</tr>
</tbody>
</table>

**RESULT**

There are 18 sample points (students) in the intervention group and 21 sample points in the control group in this study. The data was processed by statistically analysing it with the aid of SPSS.

Before the trial, an independent-samples t-test was conducted to confirm that there were no significant differences in CT skills between the control and intervention groups (p=0.123).
After the trial, three analyses were conducted to inspect the progress of the two groups. Two paired-samples T tests were run on the Pre- post test data, summarised in Table 2.

Table 2. Paired-samples T test result

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean   SD  SE</td>
<td>Mean   SD  SE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>21</td>
<td>2.76   1.55 0.34</td>
<td>3.62   1.12 0.24</td>
<td>2.905**</td>
<td>0.009</td>
</tr>
<tr>
<td>Intervention</td>
<td>18</td>
<td>3.50   1.34 0.32</td>
<td>4.39   1.04 0.24</td>
<td>4.973***</td>
<td>0.000</td>
</tr>
</tbody>
</table>

*p<.05, **p<.01, ***p<.001

The analysis yielded a significant difference (t=2.905, p=0.009) in the marks of the score between the pre-test (M=2.76, SD=1.55) and post-test (M=3.62, SD=1.12) of the control group. It also yielded a significant difference (t=4.973, p=0.000) between the pre-test (M=3.50, SD=1.34) and post-test (M=4.39, SD=1.04) of the intervention groups.

The result suggests that both hardware-based text programming and graphical programming had an effect on promoting student’s computational thinking.

To follow up the effect difference between the two groups, an independent-samples T tests was conducted on the effect of the intervention on the post-test score whilst controlling for the pre-test score (see Table 3).

The result confirmed that there was a significant difference in the post-test score between the control (M=3.62, SD=1.12) and intervention (M=4.39,SD=1.04) groups (t=2.62, p=0.013) while there no significant difference was found in pre-test (t=1.58, p=0.123), which indicated that hardware-based graphical programming had a significantly better effect on promoting CT skills than hardware-based text programming.

Table 3. Post-test independent-sample T tests result

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean   SD</td>
<td>t  Sig.</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Control</td>
<td>21</td>
<td>3.62   1.12</td>
<td>1.58 0.123</td>
<td>3.62</td>
<td>1.12</td>
</tr>
<tr>
<td>Intervention</td>
<td>18</td>
<td>3.50   1.34</td>
<td></td>
<td>4.39</td>
<td>1.04</td>
</tr>
</tbody>
</table>

*p<.05, **p<.01, ***p<.001

To verify the results of the primary two analyses, we scored students final works as an additional study. Each work was graded by three teachers and the final score was the mean of the ratings.

A summary of the means, standard deviations and an independent-sample T tests result is given in Table 4.
Table 4. Final work independent-sample T tests result

<table>
<thead>
<tr>
<th>Item</th>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUM</td>
<td>Intervention</td>
<td>11</td>
<td>14.33</td>
<td>2.39</td>
<td>17.33</td>
<td>11.00</td>
<td>0.077</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>13</td>
<td>12.54</td>
<td>2.35</td>
<td>15.67</td>
<td>8.67</td>
<td></td>
</tr>
<tr>
<td>Novelty</td>
<td>Intervention</td>
<td>11</td>
<td>2.94</td>
<td>0.57</td>
<td>3.67</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>13</td>
<td>2.54</td>
<td>0.94</td>
<td>4.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Logicality</td>
<td>Intervention</td>
<td>11</td>
<td>2.67</td>
<td>0.59</td>
<td>3.67</td>
<td>1.67</td>
<td>0.552</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>13</td>
<td>2.54</td>
<td>0.44</td>
<td>3.33</td>
<td>1.67</td>
<td></td>
</tr>
<tr>
<td>Robustness</td>
<td>Intervention</td>
<td>11</td>
<td>2.76</td>
<td>0.54</td>
<td>4.00</td>
<td>2.00</td>
<td>0.947</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>13</td>
<td>2.75</td>
<td>0.45</td>
<td>3.67</td>
<td>1.67</td>
<td></td>
</tr>
<tr>
<td>Integrity</td>
<td>Intervention</td>
<td>11</td>
<td>2.91</td>
<td>0.54</td>
<td>3.67</td>
<td>2.00</td>
<td>0.264</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>13</td>
<td>2.67</td>
<td>0.49</td>
<td>3.67</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>Complexity</td>
<td>Intervention</td>
<td>11</td>
<td>2.82</td>
<td>0.89</td>
<td>4.00</td>
<td>1.67</td>
<td>0.026</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>13</td>
<td>2.05</td>
<td>0.69</td>
<td>3.33</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

Each mean improvement for the intervention group students was higher than the control group, especially in complexity dimension. As can be seen in the Box-plots in Figure 1, the distribution of high scores of the intervention group is more than the control group. This difference is also statistically significant in complexity dimension, as determined through an Independent-samples T-test (t = 2.39, p = 0.026), which indicates that the intervention group students accomplished more complicated programs in their work, which has a close relationship with computer thinking.

![Box-plot of complexity score](image)

**Figure 1. Box-plot of complexity score**

**DISCUSSION**

In the current study, we examined the effects of programming education based on micro:bit on middle school student’s CT skills. Three main conclusions have been drawn. The first conclusion is that programming education based on micro:bit, using either graphical or textual programming tools, can effectively improve student’s CT skills. This finding is consistent with viewpoint in literature in the fields of programming and CT that programming
is more than just coding; it exposes students to computational thinking which involves problem-solving using computer science concepts like abstraction and decomposition (Lye & Koh, 2014). It is worth noting that the pedagogy in the programming activities is an important factor which determines how student think in the learning process.

The second conclusion indicates that graphical programming has a better effect on promoting CT skills. In a manner of speaking, the advantage of graphical programming, such as block-based interaction interface, which means simpler programming syntax, easier debugging and less mistake, is the key to this outcome.

In addition, we found that the Intervention group wrote programs more effectively when we compared the cost time which the two group took to complete a programming task. According to the control group students, they spent a lot of time debugging programs, rather than thinking about the structure and functionality of the programs. So using graphical programming tools means that students can focus on the logic of programming without being bothered by the details of the difficult grammars.

The third conclusion is that the intervention group students had better performance in using programming to complete a work, which means that graphical programming is more suitable for comprehensive and problem-solving learning tasks. From the analysis above we found a significant difference in complexity as described by the two groups.

There are two possible reasons according to the description of the participants. One is the frequent debugging using textual programming, which caused students to come up with a patchwork of code to complete the work. The second is that graphical programming can better help students decompose a complex task into small, easy tasks, and clarify the internal logic of a program.

These findings are consistent with evidence in the literature review, which showed that block language eliminates syntax errors, allowing users to focus on interesting problems right away, rather than struggling merely to get their program to compile (Maloney, Resnick, Rusk, Silverman, & Eastmond, 2010). What’s more, the graphical programming elements provided by the visual problem-solving environment may further support the decomposition of computational problems, the assembly of control flow structures, and the testing of chunks of novices' self-generated instructions (Maloney et al., 2010).

One limitation of the current study is that the class time is short and the number of participants is small. A more significant effect may be detected after a long time of training, and increasing the number of participants will make the results of the study more reliable. Future studies should also address some of the questions of how teaching strategies impact on CT skills. Another is whether it is possible to achieve the same effect by expanding the 16 class hours training to a regular semester course.

REFERENCES


HOTSPOTS IN RESEARCH ON STEM EDUCATION IN CHINA

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ABSTRACT

Education in science, technology, engineering, and mathematics (STEM) is a model used to deliver an integrated science education and has become more important in China in the past five years. According to the new national standards released last year, STEM education was officially employed for the first time. Although research on STEM education has been increasing in major Western countries for decades, less is known about its development in China due to the language barrier as most international researchers do not understand Mandarin. This study intends to fill this gap in the current literature by identifying the research hotspots in relation to STEM education in a Chinese context. A co-word analysis, a clustering analysis, and a social network analysis were performed in this study to highlight the current discourses about STEM education in China. The findings of this study show that, while STEM education has become prominent in both the policy and research agendas in China, it is still early on into its initial stage. Compared to worldwide research on STEM education, studies conducted by Chinese researchers have a narrower range of foci. This study provides a snapshot of the research landscape for the international scholars who are trying to grasp the mainstream discourses on STEM education in China.

Keywords: STEM education, research hotspots, co-word analysis, China

INTRODUCTION

Science education has always been prioritised throughout students’ schooling in China, considering the essential role of science and technology (S&T) in the national economy and the related social values. In order to provide a high-quality science education to all school-age children in China, the central government has developed a wide range of policies and strategies at different levels and invested substantial resources in reforming curricula and assessments.

Learning from internationally prevalent practices is an important part of the educational reforms taking place in China. In particular, STEM education, which has been actively promoted in the United States and other major Western countries for decades, has finally attracted increasing attention in the Chinese school system.

In February 2017, China’s Ministry of Education (MoE) issued its new Compulsory Education Primary Science Curriculum Standards, in which STEM, as a concept, is officially applied for the first time. Due to the language barrier, research focusing on STEM education in China has rarely been published in English, which limits the communication between the Chinese and international academic communities. Within this situation, this study conducted
a co-word analysis of the available studies on STEM education in China in order to identify the hotspots.

**RESEARCH ON STEM EDUCATION IN THE WEST**

The term STEM was coined by Judith A. Ramaley, a former director of the National Science Foundation’s (NFS) Education and Human Resources Division, to refer to science, technology, engineering, and mathematics curriculums (Breiner, Harkness, Johnson, & Koehler, 2012). Although the STEM movement has gained wider prominence in the past two decades, the call for strengthening science and mathematics education in the United States started in the early 1980s (e.g., see the National Commission on Excellence in Education [NCEE], 1983).

The push for STEM education in U.S. schools appears to have started from two major concerns: the STEM pipeline problem and students’ disappointing grades in science and mathematics. By country or region, it is estimated that only six per cent of undergraduates in America major in engineering compared to 12 per cent of European students, 20 per cent of Singaporean students, and 40 per cent of Chinese students (Koehler, Biins, & Bloom, 2015). The declining enrolment in STEM disciplines is expected to create a shortage of a qualified U.S. STEM workforce in the near future, which could result in the loss of America’s technology and engineering leadership to other countries (Becker & Kyungsuk, 2011; Dugger, 2010).

In addition to the insufficient participation by U.S. students in STEM studies, a large majority of U.S. secondary school students failed to achieve proficiency in mathematics and science, and many are taught by teachers lacking adequate subject matter knowledge (Kuenzi, 2008). Moreover, there are significant gaps in achievement levels between student population groups: Black and White, Hispanic and White, and high-poverty and low-poverty (U.S. National Research Council, 2011). Given these factors, the goals for the K-12 STEM education in the United States are three-fold: to expand the participation in STEM fields, to broaden the participation of women and minorities in STEM fields, and to increase STEM literacy for all students (National Research Council, 2011).

In 2016, Zhan and Xu conducted a literature analysis of available studies on STEM education across the world to identify the trends and hotspots in this research field. In their study, they used ‘STEM Education’ as the subject word to search available publications in the ERIC database between 2005 and 2015, resulting in 2,430 studies. The keywords were used to run a co-word analysis that produced the co-occurrence similarity matrix for further clustering analysis. The results show that research on STEM education primarily centred on four themes: 1) independent STEM discipline education, 2) research methods in STEM education and development, 3) reform in STEM education, and 4) STEM curriculum.

Regarding the independent STEM disciplines, science and engineering attracted the most attention from researchers worldwide. A variety of methods have been employed in research on STEM education, including quantitative, qualitative, mixed methods, case study and comparative study. In relation to the development and reform of STEM education, these studies explored the effects of education reforms, professional development of STEM teachers, gender difference and students’ interests and career aspirations. The STEM curriculum themes include topics such as curriculum evaluation, effects of the STEM curriculum, and partnerships in STEM education. The four broad themes indicate the major foci and directions of current studies on STEM education worldwide.
METHODOLOGY

In order to identify the hotspots in research on STEM education in China, a co-word analysis was conducted. This kind of analysis is a quantitative content analysis method that has been widely used in many fields of study, including education (e.g., Alzafari, 2017) to map the knowledge structure of a research field, identify the research domain topics, and explore the characteristics and development of the evolution of specific subjects (Chang et al., 2017; Ding, Chowdhury, & Foo, 2001).

Given that the majority of research studies on STEM education in China are published in Chinese, the China National Knowledge Infrastructure (CNKI) was selected as the database for identifying available articles for this study. Ideally, peer-reviewed articles should be included exclusively in this study to make sure only high-quality studies are included. However, the peer-review mechanism has not yet been established in Chinese academic communities.

In this case, the search was limited to articles published in core journals and journals indexed by Chinese Social Sciences Citation Index (CSSCI). ‘STEM education’ and ‘STEAM’ were used separately as the searching term included in the subject of the articles. After removing duplicates and irrelevant articles, the search process resulted in 155 articles. Given the small number of available studies, an extended search in the CNKI-Master’s theses and doctoral dissertations database was conducted using the same searching terms.

This resulted in another 54 studies. Assuming that there could be research about STEM education in China published in English, another search using variations and combinations of ‘STEM education,’ ‘Science, technology, engineering, math,’ ‘China,’ and ‘Chinese’ as search terms was conducted in the EBSCO database. This resulted in 16 peer-reviewed articles. A total of 225 studies were included in the next step of abstract review and coding.

Two major methods are used to identify the keywords used in co-word analysis: using the article’s keywords provided by the author or the keywords extracted manually by the researcher from the title, abstract and the full text. This study adopted the later approach to screen and code the abstract of the 225 articles and extract the keywords for each article. This process also aims to identify the samples for co-word analysis by excluding irrelevant articles. Specific categories used for the abstract coding are presented in Table 1. A total of 195 of the 225 (87%) studies reviewed were retained for co-word analysis.

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition or example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study type</td>
<td>Empirical or Theoretical</td>
</tr>
<tr>
<td>Study context</td>
<td>Australia, Canada, China, OECD, Thailand, U.S., UK, Comparative study, Non-specified context</td>
</tr>
<tr>
<td>Educational level</td>
<td>K-12, Preschool, Preschool and Primary, Primary, Secondary, Primary and Secondary, Post-secondary, Secondary and Postsecondary, VET, non-specified level</td>
</tr>
<tr>
<td>Topic (Keywords)</td>
<td>e.g., STEAM, STEM teaching unit development, overview of STEM development, policy analysis, maker movement, community engagement, physics, engineering, evaluation of STEM teaching effectiveness, etc.</td>
</tr>
</tbody>
</table>

A total of 82 keywords were extracted and the overall frequency was 366. Considering that STEM education is an emerging research area in China and the number of available
studies is relatively small, a decision was made to select all keywords with a frequency higher than 5 as high-frequency terms. This process resulted in 19 high-frequency keywords and a 19*19 co-occurrence matrix was produced for further clustering analysis and social network analysis (SNA), which is a method to study the relationship among a set of factors and to analyse the connections with regard to network theory (Ravikumar, Agrahari, & Singh, 2015). The co-occurrence matrix was imported into Ucinet6.0 and converted into Cosine similarity matrices, which were used to conduct the hierarchical clustering analysis based on the simple average agglomeration algorithm.

Clustering is a method that has the merit of grouping objects by similarity or dissimilarity (Ravikumar et al., 2015; Zhao et al., 2018). Keywords with a high correlation with each other have a tendency to be put into the same cluster. A dendrogram was produced and clusters were categorised accordingly to the hotspots indicate in the research on STEM education in China.

RESEARCH HOTSPOTS ON STEM EDUCATION IN CHINA

Development and Features of Research on STEM Education in China

Descriptive analysis shows that in the most recent eight years, Chinese researchers have paid increasing attention to STEM education. The number of publications increased gradually from 2 in 2011 to 44 in 2016. In 2017, the number of studies doubled compared to 2016, possibly due to the release of the new standards in which STEM as a concept was officially employed for the first time.

China Educational Technology is the leading journal in this field and publishes the largest number of research studies, which account for 12.2 per cent of its total publications. East China Normal University published the most Master’s and Doctoral studies on this topic, accounting for 16.7 per cent of the total of 54 theses and dissertations. Less than one-third of the studies incorporated empirical data. Nearly half of all studies investigated STEM education in the Chinese context, while another 40 per cent introduced the U.S. policies and practices in the studies. One-third did not specify the educational level it focused on, and one-fifth focused on the primary and secondary level and 12.3 per cent on the primary level, followed by post-secondary (11.3%) and secondary (10.8%) levels. Another 9.2 per cent studied STEM education in the K-12 setting. Figure 1 summarises selected key features of the available studies.

![Figure 1. Selected key features of research on STEM education in China between 2011 and 2018](image)

Research Hotspots Suggested by Keyword Clusters

The 19 identified high-frequency keywords are listed in Table 2. The cumulative frequency percentage of these keywords accounts for 73.79 per cent of the total extracted
keywords, which indicates these terms could represent the research hotspots on STEM education in China in the past seven years. Based on the hierarchical clustering analysis, three groups with varying number of keywords in addition to one isolated keyword are indicated in the dendrogram (Figure 2). The first group includes four keywords: STEM teacher education, STEM teaching strategies, quality assurance and evaluation, and policy analysis. This group focuses on the broad aspects of STEM education. The second group includes five keywords: STEAM, Challenges, Community engagement, Maker education, and Overview of STEM education development. Keywords included in this group reflect the concepts related to STEM education such as STEAM and Maker education, and other key issues in relation to STEM education.

The third group includes the largest number of keywords: Physics, Robotics, Engineering, 3D printing, STEM teaching effectiveness, STEM teaching unit development, STEM-related capabilities, Model of STEM curriculum, and Integration of S.T.E.M. This group has a curriculum focus centring on specific subject areas and topics under the umbrella of STEM education. The isolated keyword is Gender difference. It is reasonable to treat Gender difference as a stand-alone keyword since it is a common issue that draws researchers’ attention across fields.

### Table 2. High-Frequency Keywords Extracted from Available Studies on STEM Education

<table>
<thead>
<tr>
<th>ID</th>
<th>Keywords</th>
<th>Frequency</th>
<th>Percentage</th>
<th>Cumulative percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>STEM teaching unit development</td>
<td>35</td>
<td>9.56</td>
<td>9.56</td>
</tr>
<tr>
<td>B</td>
<td>Policy analysis</td>
<td>25</td>
<td>6.83</td>
<td>16.39</td>
</tr>
<tr>
<td>C</td>
<td>STEAM</td>
<td>24</td>
<td>6.56</td>
<td>22.95</td>
</tr>
<tr>
<td>D</td>
<td>Maker education</td>
<td>20</td>
<td>5.46</td>
<td>28.41</td>
</tr>
<tr>
<td>E</td>
<td>STEM teaching effectiveness</td>
<td>19</td>
<td>5.19</td>
<td>33.60</td>
</tr>
<tr>
<td>F</td>
<td>Integration of S.T.E.M.</td>
<td>19</td>
<td>5.19</td>
<td>38.79</td>
</tr>
<tr>
<td>G</td>
<td>Overview of STEM education development</td>
<td>19</td>
<td>5.19</td>
<td>43.98</td>
</tr>
<tr>
<td>H</td>
<td>Model of STEM curriculum</td>
<td>18</td>
<td>4.92</td>
<td>48.9</td>
</tr>
<tr>
<td>I</td>
<td>Quality assurance and evaluation</td>
<td>18</td>
<td>4.92</td>
<td>53.82</td>
</tr>
<tr>
<td>J</td>
<td>Community engagement</td>
<td>13</td>
<td>3.55</td>
<td>57.37</td>
</tr>
<tr>
<td>K</td>
<td>STEM-related capabilities</td>
<td>9</td>
<td>2.46</td>
<td>59.83</td>
</tr>
<tr>
<td>L</td>
<td>Challenges</td>
<td>8</td>
<td>2.19</td>
<td>62.02</td>
</tr>
<tr>
<td>M</td>
<td>Gender difference</td>
<td>8</td>
<td>2.19</td>
<td>64.21</td>
</tr>
<tr>
<td>N</td>
<td>3D printing</td>
<td>8</td>
<td>2.19</td>
<td>66.4</td>
</tr>
<tr>
<td>O</td>
<td>Engineering</td>
<td>6</td>
<td>1.64</td>
<td>68.04</td>
</tr>
<tr>
<td>P</td>
<td>STEM teacher education</td>
<td>6</td>
<td>1.64</td>
<td>69.68</td>
</tr>
<tr>
<td>Q</td>
<td>Robotics</td>
<td>5</td>
<td>1.37</td>
<td>71.05</td>
</tr>
</tbody>
</table>
Another way to understand the relationship of these high-frequency keywords is through SNA. Table 3 presents the degree, betweenness and closeness centrality of the 19 high-frequency keywords and indicates the importance of these keywords from different perspectives. In the network of research on STEM education in China, 11 keywords have a degree of centrality above the average value of 16.11. Six keywords, including STEM teaching unit development, Maker education, Overview of STEM education development, Model of STEM curriculum, Quality assurance and evaluation, and Community engagement display the highest degree centrality value of 18, which indicates they are the current foci of studies on STEM education.

These six keywords also display the highest betweenness centrality value of 1.56, which implies they also have the strongest mediating role in the network. As shown in Table 3, two keywords—3D printing and Engineering—both present the top two closeness centrality value of 23.00, which suggests they have the closest relationship with all other keywords. A sociogram is drawn to help visualise the network of research on STEM education in China. As shown in Figure 3, the size of node indicates the keyword’s degree centrality.

Figure 2. Dendrogram of High-Frequency Keywords Using Simple Average Agglomeration

CONCLUSION

This study indicates that STEM education has gained increasing importance in policy, practice and research agendas in China. In research on STEM education, a significant number of the existing studies introduces other countries’ experiences. The co-word analysis results
show that compared to worldwide research on STEM education, studies conducted by Chinese researchers have a smaller range of foci.

Hot topics discussed by international researchers, as identified in Zhan and Xu’s (2016) study, are also investigated in the Chinese context, such as STEM curriculum development, effectiveness of STEM teaching, community engagement and STEM teacher education. In addition, gender differences in STEM education and engineering education are key issues for researchers in China and in other countries. The findings of this study provide a snapshot of the research landscape so that international scholars can grasp the mainstream discourses about STEM education in China.

<table>
<thead>
<tr>
<th>ID</th>
<th>Keywords</th>
<th>Degree</th>
<th>Betweenness</th>
<th>Closeness</th>
</tr>
</thead>
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<tr>
<td>A</td>
<td>STEM teaching unit development</td>
<td>18</td>
<td>1.56</td>
<td>18.00</td>
</tr>
<tr>
<td>B</td>
<td>Policy analysis</td>
<td>17</td>
<td>1.22</td>
<td>19.00</td>
</tr>
<tr>
<td>C</td>
<td>STEAM</td>
<td>14</td>
<td>0.00</td>
<td>22.00</td>
</tr>
<tr>
<td>D</td>
<td>Maker education</td>
<td>18</td>
<td>1.56</td>
<td>18.00</td>
</tr>
<tr>
<td>E</td>
<td>STEM teaching effectiveness</td>
<td>14</td>
<td>0.38</td>
<td>22.00</td>
</tr>
<tr>
<td>F</td>
<td>Integration of S.T.E.M.</td>
<td>17</td>
<td>1.12</td>
<td>19.00</td>
</tr>
<tr>
<td>G</td>
<td>Overview of STEM education development</td>
<td>18</td>
<td>1.56</td>
<td>18.00</td>
</tr>
<tr>
<td>H</td>
<td>Model of STEM curriculum</td>
<td>18</td>
<td>1.56</td>
<td>18.00</td>
</tr>
<tr>
<td>I</td>
<td>Quality assurance and evaluation</td>
<td>18</td>
<td>1.56</td>
<td>18.00</td>
</tr>
<tr>
<td>J</td>
<td>Community engagement</td>
<td>18</td>
<td>1.56</td>
<td>18.00</td>
</tr>
<tr>
<td>K</td>
<td>STEM-related capabilities</td>
<td>16</td>
<td>0.78</td>
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<tr>
<td>L</td>
<td>Challenges</td>
<td>17</td>
<td>1.12</td>
<td>19.00</td>
</tr>
<tr>
<td>M</td>
<td>Gender difference</td>
<td>17</td>
<td>1.12</td>
<td>19.00</td>
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<tr>
<td>N</td>
<td>3D printing</td>
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<td>0.48</td>
<td>23.00</td>
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<td>Engineering</td>
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<tr>
<td>P</td>
<td>STEM teacher education</td>
<td>17</td>
<td>1.12</td>
<td>19.00</td>
</tr>
<tr>
<td>Q</td>
<td>Robotics</td>
<td>14</td>
<td>0.47</td>
<td>22.00</td>
</tr>
<tr>
<td>R</td>
<td>Physics</td>
<td>14</td>
<td>0.00</td>
<td>22.00</td>
</tr>
<tr>
<td>S</td>
<td>STEM teaching strategies</td>
<td>15</td>
<td>0.44</td>
<td>21.00</td>
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</table>
REFERENCES


ABSTRACT

This paper shares the results of the first of a series of diagnostic assessments focused on promoting the teaching and learning of calculation strategies for Grade 3 learners in South Africa. The series of assessments address calculation strategies such as bridging through ten, jump strategies and doubling and halving. They are accompanied by reasoning chains for teacher use in eight ten-minute mental mathematics sessions designed to develop learner fluency in related skills and the focal strategy. The assessments are then used as a post-test to gauge the improvement in student learning. Initial trials were conducted for the ‘bridging through ten’ strategy in six classes across two provinces in South Africa. Results show positive learner outcomes. The format of these assessments and the accompanying reasoning chains are informing the national landscape where summative end year assessments have been abandoned in favor of assessments that can inform teaching throughout the year.

Keywords: Diagnostic assessment; reasoning chains; strategic thinking

INTRODUCTION AND CONTEXT

Mathematics education in South Africa is argued to be ‘in crisis’ (Fleisch, 2008) with learners performing below expectations on national, regional and international studies. Furthermore, performance is highly polarised indicating among the greatest performance gaps internationally in mathematics between rich and poor (Reddy, 2006). Spaull and Kotze (2015) argue that by Grade 4 a majority of learners are already two grades behind expectations.

A factor widely identified as contributing to poor performance and weak progression is a lack of number sense and a dominance of concrete methods of calculation. Schollar’s (2008) study for example found that 79.5% of the Grade 5 test scripts from 154 schools across all 9 provinces relied on simple unit counting to solve problems. Our own research across the multiple schools concurs with this and we have widespread evidence of learners using drawn tallies for simple calculations such as 10+10+10 (e.g., Weitz & Venkat, 2013).

The implementation of the Annual National Assessments (ANAs) by the Department of Basic Education in 2011 for Grades 1-6 and 9 did little to address poor performance and weak number sense. As Diamond (2007, p. 306) argues while high-stakes assessments ‘may get teachers’ attention, they provide few resources for addressing issues of inequality in schools.’

The ANAs were criticised by teachers and teacher unions and ended with refusal by some schools to write them. They were abandoned in 2016. Among the criticisms was that they did little to encourage the teaching of number sense and the focus on correct answers fed
into acceptance of counting based strategies thus perpetuating rather than addressing problems of progression (Graven, Venkat, Westaway, Tshesane, 2013; Graven & Venkat, 2014).

South Africa’s national curriculum policy however includes the development of number sense which is connected with developing mental models and strategies for computation. For example, the Curriculum and Assessment Policy document (CAPS) includes that Mathematics should “develop mental processes that enhance logical and critical thinking, accuracy and problem solving that will contribute in decision making” (DBE, 2011, 8-9).

The document includes a range of basic facts (fluencies) that learners should know instantly (such as adding ten to a number; knowing number bonds to ten and so forth) as well as a range of calculation strategies (such as Bridging through 10 and Doubling and Halving). Through our professional development work we focused on supporting teachers to understand (and use) the relationship between using such fluencies and strategies to move students beyond one to one concrete methods of calculation.

The Foundation Phase diagnostic assessment investigation emerged from this context and was led by the two South African Numeracy Chair (authors) who are mandated to search for ways forward to the challenges of mathematics teaching and learning in primary schools in South Africa. While their Chairs are located in two separate universities and provinces they have worked closely together since their Chairs began in 2011 (see Graven & Venkat (2017) for a range of research based on the work of members of their research teams).

This assessment project began with an initial meeting in 2016 which was attended by members of both Chair teams, with representation from the Department of Basic Education (at national, provincial and district level), the Association of Mathematics Education of South Africa, the Southern African Association of Research in Mathematics Science and Technology Education; the Non-Government Organisation community, and two international experts in early mathematics teaching and learning: Professor Mike Askew and Professor Bob Wright.

Given widespread acknowledgement that assessment influences practice (e.g., Elmore, Ablemann & Fuhrman, 1996), absence of attention to number sense that underlies fluent, flexible and strategic mental and written working in previous Annual National Assessments was seen as problematic. Furthermore, it was noted that to shift teacher practice on a more national scale it would be important to influence national assessment practices to foreground number sense and non-concrete strategies. Knowledge of such strategies is stipulated in the national curriculum (DBE, 2011).

Our representative from the national Department of Basic Education noted that there was policy level interest in diagnostic assessment formats that could be administered with an orientation grounded in feedback loops into teaching and learning. Thus, following our week of deliberations, consensus was reached that we should investigate a possible format for the design of a series of diagnostic assessments and reasoning chains to support the teachers and learners to move beyond concrete methods of calculation to using strategic awareness of number relations and structure in ways that promote effective and efficient calculation.

We report on the final format arrived at following our ongoing deliberations and small scale piloting. We then report on the findings of our formal pilot across six classrooms in two provinces.
THEORETICAL ORIENTATION AND LITERATURE REVIEW

A socio-constructivist perspective broadly guided our deliberations and the design of our diagnostic assessments and reasoning chains. Kilpatrick, Swafford & Findell’s (2001) model of five strands of mathematical proficiency (namely: conceptual understanding, procedural fluency, adaptive reasoning, strategic competence and productive disposition) and the inter dependence of these strands broadly informed our thinking. We particularly drew on Askew’s (2012) work suggesting that it is practical to foreground, in working with teachers, fluency, reasoning and problem-solving (strategic competence) as these are the strands that are both most ‘visible’ in learner working and also useful to design for in teaching. The focus on these three strands links to the three categories of assessment used in the design of our pre- and post-diagnostic assessments, discussed below, particularly in relation to our emphasis on the interrelationship between fluencies (such as adding ten to any number) and strategies (such as using jump strategy).

In terms of designing assessment items our work was guided by earlier seminal assessment work developed in England and Australia by our two international participants namely Mike Askew and Bob Wright (respectively) and their colleagues. In particular we drew on the types of assessment items included in the Leverhulme study published as Effective Teachers of Numeracy conducted in England in the nineties (Askew, Brown, Rhodes, Wiliam & Johnson, 1997). In particular, the finding from their study that indicated having a connected understanding of mathematics is important for the effective teaching of numeracy resonated with our guiding assumptions.

We also drew on the work of Bob Wright and his colleagues who focus on using carefully constructed assessment items to enable mathematical recovery of learners falling behind grade level expectations. For example we drew on the books of Wright, Martland, Stafford, & Stanger (2006) and Wright, Martland and Stafford (2006) which focus on early numeracy assessment for teaching and intervention.

Next we explain our research design, the strategies we selected to focus on; the categories of assessment items developed and the way in which we put these together into two-week assessment-teaching cycles.

RESEARCH DESIGN

Following our initial meeting the following strategies were selected for the development of assessment items and reasoning chains:

- Bridging through ten
- Jump strategy
- Doubling and halving
- Understanding the relationship between addition and subtraction
- Re-ordering
- Compensation

These were identified within the South African Foundation Phase curriculum document (DBE, 2011) as important. Using the number line was considered an essential tool (including as a mental image) for working across these strategies. A range of fluencies were considered essential for successful use of these strategies (such as being able to: add ten to any number; double and halve numbers). Thus, for each of the above strategies we decided to design three categories of assessment items, namely: rapid recall (fluency), strategic calculating (strategic competence/ problem solving) and strategic thinking (adaptive reasoning) items.
Our focus on these three categories of items, was driven by the literature discussed above which draws attention to the usefulness of focusing on these strands as well as the lack of attention to these in South Africa in the Foundation Phase.

Rapid recall items - noted in the CAPS curriculum for mental mathematics: e.g., multiplying by 2, adding and subtracting 1, 2, 3, 4, 5 and 10 to any number; place value decompositions of number, and key fact triples between 1 and 20.

Strategic calculating items - include items such as 99 + 99 which are laborious to do in a one to one or ‘procedural’ calculation orientation – but very easy to do if the problem is recognised as one that is amenable to rounding to 100, doubling 100 and then compensating or to using a number line – written or mental – to ‘bridge through 100’ (i.e. 99 + 1 + 98 = 198 or 2 x 100 – 2 = 198).

Strategic thinking items - focused on understanding number structure, properties and relationships, and the behaviour of operations. Items focus on using knowledge of number and relationships to limit the extent of calculation needed: e.g., Given 43 + 138 = 181 then what is 181 – 43 = __ ?

In follow-up meetings between smaller groupings of participants, possible formats for diagnostic assessment were discussed. Agreement was reached on the format of a 2-week cycle with a pre- and post- ‘test-let’ format focused on each of the above six strategies. (Data from the first ‘bridging through ten’ is shared in this paper). The two-week cycle commenced as follows:

- 2-week block begins and ends with a test-let in time limited format
- teacher marking follows guided by lesson starter ‘reasoning chain’ teaching activities aimed at developing fluencies and strategies in ten minute sessions on the eight days following the pre-test
- re-test - provides feedback on learning and, hence, success of teaching

In an initial pilot by the first author (in three classes in one Eastern Cape school) challenges were noted in the administration of the assessments and the teaching of the ‘bridging through ten’ reasoning chains. Thus, the format of the assessment items and time available for each category of items was changed resulting in three single pages of items administered separately as follows:

- 20 rapid recall items to be completed in two minutes (E.g., 10 = 7 + _; 50 + 6 = and 40 – 7 =)
- 5 strategic calculating items to be completed in one minute (e.g., 56 + 8 = _ and 93-7 = , the first two items were accompanied by a number line for example:

  ![Number Line Example](image)

- 5 strategic thinking items to be completed in one minute (E.g., 98 + 56 = 98 + 2 + _)

The assessment of the ‘bridging through ten strategy’ in the above format was then conducted with classes across two provinces (discussed below). Assessments were then marked providing feedback to teachers on strengths and weaknesses of the learners and the
eight adapted ten-minute session lesson starter outlines were provided to teachers (following 20-40 minute initial conversations with them about the use of the lesson starter outlines). Thereafter learners were re-assessed on the test in the same way.

An example of part of day one’s lesson starter outline is given below:

First minute mental warm up – playing games for bonds to ten and multiples of ten. E.g., I say 3 you say 7; I say 6 you say ?; What’s the next ten after 47? 58? 32? – emphasis that this is not rounding to the nearest ten but finding the next ten on the number line.

Then consider: 46 + 7. We can show this on a number line:

We have to jump forwards 7. Let’s jump to the next ten rather than jumping in 1s. What is the next ten after 46? Then show the 50 on the number line above. What do we add to get to the 50? Show this +4 with an arrow in the number line. We have added 4 but we need to add 7. How much more must we add? Show the +3 with an arrow on the number line from 50 to ?. So 50 + 3 is ? Show the 53 on the number line. So 46 + 7 = 46 + 4 + 3 = 53. Do another example and have learners solve a few more using this method independently.

The authors sought and obtained access to two government primary schools in Gauteng and one government primary school in the Eastern Cape to trial the adapted test-let and reasoning chain activities. Below we share the results of our initial trials based on administering this test-let twice in a fortnight period (or in some cases just over as weather conditions in the Eastern Cape school caused delay in post testing), with teachers in government schools in these two provinces.

South African state schools are classified into five quintiles based on a range of catchment area factors (e.g. income, unemployment rate). Quintile 1 schools are the poorest while quintile 5 the ‘least poor’ (DoE, 1998). The two Gauteng schools were a township Quintile 1 school and a suburban Quintile 5 school. One township Quintile 3 school participated in the Eastern Cape trial.

In this school, two Grade 3 teachers and one Grade 2 teacher (who requested inclusion) participated. Since the assessments were trialed toward the end of the Grade 2 academic teaching year it was considered appropriate for these learners to participate.

While the tests were designed at Grade 3 level all fluencies and strategies assessed apply also to Grade 2 learners. Due to limited space, we combine results for the classes in each province below although we have kept the Grade 2 class results separate. The latter results indicate possible broader applicability of the diagnostic test-let assessment/ reasoning chain format beyond Grade 3.

RESULTS AND DISCUSSION

Table 1 and Table 2 below provide the results for the mean average pre- and post-percentage obtained by participating learners across the two provinces.
Table 1. Eastern Cape Grade 3 and Grade 2 outcomes

<table>
<thead>
<tr>
<th></th>
<th>Rapid Recall (20 items: 2 minutes)</th>
<th>Strategic Calculating (5 items: 1 minute)</th>
<th>Strategic Thinking (5 items: 1 minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MeanPre%</td>
<td>MeanPost%</td>
<td>MeanPre%</td>
</tr>
<tr>
<td>(n=65)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 3</td>
<td>26.7</td>
<td>40.7</td>
<td>11.7</td>
</tr>
<tr>
<td>(n=30)</td>
<td>31.2</td>
<td>56.4</td>
<td>10.3</td>
</tr>
</tbody>
</table>

Table 2. Gauteng Grade 3 outcomes

<table>
<thead>
<tr>
<th></th>
<th>Rapid Recall (20 items: 2 minutes)</th>
<th>Strategic Calculating (5 items: 1 minute)</th>
<th>Strategic Thinking (5 items: 1 minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MeanPre%</td>
<td>MeanPost%</td>
<td>MeanPre%</td>
</tr>
<tr>
<td>All (n=134)</td>
<td>56.3</td>
<td>75.3</td>
<td>37.6</td>
</tr>
</tbody>
</table>

The differences in performance on assessments across the two provinces cohere with national data which indicates Gauteng as one of the top performing provinces in the country and the Eastern Cape as one of the lowest. This also reflects the difference in economic wealth of these provinces with Gauteng being the wealthiest of South Africa’s nine provinces and the Eastern Cape being among the poorest. There are several interesting points to make in relation to the above tables.

Predictably, and in both provinces, pre-test performance was highest in the rapid recall cluster of items, and lower in the other two item cluster types. What the pre-test results also point to though is problematic gaps within the rapid recall category given that these items represent fundamental skills that the curriculum expects almost all children to have mastery of, as the base upon which more strategic calculating and thinking are built. Our data points to little more than a third of these items being answered correctly in three of the four Grade 3 classes in this sample. Given this, and the broader evidence alluded to earlier, the weaker pre-test performance on the Strategic Calculating and Strategic Thinking items is predictable.

Post-test outcomes point to pleasing gains in both provinces in the Grade 3 classes. In the Eastern Cape, gains were seen across all three item categories; in Gauteng, there was a small drop in performance in the strategic calculating category in the township school, but substantial increases in all of the other categories across both schools. The feedback from the teachers involved also suggested positive experiences of working with the reasoning chains, and we saw reasonably good implementation in the mental mathematics starter sections that we observed.

CONCLUDING REMARKS: WHERE TO FROM HERE?

These findings suggest that the diagnostic test-let/reasoning chain activity model can contribute to improvements in performance in ways that support the development of number sense. Our recommendation for the next stage would be a broader and more nationally representative DBE-led trial of the Bridging through 10 and Doubling and Halving test-lets and Reasoning Chain activities that have been developed.

Our suggestion for this trial would be to work via Foundation Phase provincial and district Mathematics specialists to support the running of trials in each district using the same model used in the preliminary trial. We could provide an outline of processes for Subject
Advisers to support this. Our sense is that broader and more representative trials would be needed to decide the robustness of the promising results that we have seen, prior to deciding the feasibility for roll-out of the diagnostic test-let format.

Acknowledgements

Thanks to our broader team mentioned in the paper and the NRF for their support of this work.

REFERENCES


ABSTRACT

Strong numeracy skills are crucial in order for teachers to successfully integrate science, technology, engineering, and mathematics (STEM) in their teaching. In this study, we explored pre-service teachers’ views of and capabilities in numeracy. Students in a Master of Teaching program at a prestigious Australian university who were enrolled in a unit about numeracy teaching and learning completed questionnaires before and after completing the unit about their views of and capabilities in numeracy. Here, we focus on the pre-unit questionnaire data from 2017 and 2018, drawing comparisons between the responses of secondary pre-service teachers with STEM ($n = 18$) and non-STEM ($n = 25$) subject area specialisms. We analysed two calculation questions (including the linked questions about the participants’ confidence in their responses) and three questions about participants’ views of numeracy and mathematics, to see if there were differences in the response patterns of the two groups. While the differences between the STEM and non-STEM groups were generally not statistically significant, there was a consistent pattern of the STEM students being more knowledgeable about numeracy and confident in their numeracy capabilities. These findings point to the importance of numeracy units in preparing all pre-service teachers to incorporate both numeracy and STEM in their teaching.

Keywords: Numeracy, pre-service teachers, STEM vs. non-STEM specialisms

INTRODUCTION

As argued by the STEM Partnerships Forum (2017), which is led by Australia’s Chief Scientist, Alan Finkel, primary and secondary schools are not providing adequate STEM education, and students are not participating in – or achieving in – these subjects sufficiently well. To address these issues, the STEM Partnerships Forum (2017) suggested that these subjects need to be made “so compelling, so stimulating and so exciting that the student cannot help but be inspired to take up these subjects. This will require teachers who are confident in their discipline” (p. 5). The STEM Partnerships Forum further asserted that “An increasing focus on STEM skills should build on strong foundations in literacy and numeracy and be a part of a rich school education” (p. 6).

The importance of numeracy for teachers and students has also been recognised by several key educational bodies in Australia in recent years. Numeracy is one of seven general capabilities in the Australian Curriculum (Australian Curriculum, Assessment and Reporting Authority [ACARA], n.d.), which means that it is the responsibility of all teachers to develop students’ numeracy capabilities. Numeracy is also a requirement in the Australian Professional Standards for Teachers (Australian Institute for Teaching and School Leadership [AITSL], 2017), with Standard 2.5 relating to developing numeracy capabilities in students
and Standard 5.4 relating to interpreting student data. To assess whether pre-service teachers have adequate literacy and numeracy skills, the Australian Council for Education Research (ACER) introduced the Literacy and Numeracy Test for Initial Teacher Education (LANTITE) in 2016. All pre-service teachers must pass the LANTITE test – with passing indicating that they are in the top 30% of the Australian adult population with regard to personal literacy and numeracy skills – prior to graduation (ACER, n.d., 2018).

Here, we focus on pre-service teachers’ numeracy views and capabilities. If teachers are prepared in such a manner that they are capable, confident, and knowledgeable about numeracy, it will serve them well in all of their teaching responsibilities, particularly those related to STEM, as STEM teaching is strongly predicated on numeracy capabilities and confidence. To explore these topics, we conducted research in which pre-service teachers at a prestigious Australian university completed questionnaires about their numeracy capabilities, confidence, and understandings, prior to and after completing a unit about numeracy teaching and learning.

GOALS AND OBJECTIVES

The goal of this paper is to investigate whether there are differences between secondary pre-service teachers with STEM and non-STEM subject area specialisms, in terms of their views of, confidence in, and capabilities in numeracy.

THEORETICAL FRAMEWORK

The present study was informed by the Australian Curriculum’s expectations (ACARA, n.d.) that teachers of all subject areas develop their students’ numeracy capabilities, as well as by the AITSL (2017) requirements related to graduating teachers’ personal numeracy capabilities. Guiding the development of the unit of teaching that the participants were about to commence, and hence the study reported here, was the 21st Century Numeracy Model (Goos, Geiger, & Dole, 2014), a model that centres on using mathematics in context. The model is broadly aligned with a social constructivist theoretical stance on learning.

REVIEW OF LITERATURE

Steen (2007), a ground-breaking U.S. author on numeracy, clearly distinguished between mathematics (abstract) and numeracy (concrete and tangible) and claimed that “the need to understand and be able to use mathematics in daily life and work has never been greater” (p. 17). Current Australian Curriculum expectations are consistent with Steen’s view. As noted above, all teachers are charged with the responsibility of developing students’ numeracy skills. Together with the mandated pre-graduation personal numeracy test now in place, ongoing concerns about prospective teachers’ numeracy understandings and capabilities are being enacted.

While internationally there is a large body of research on teachers’ and prospective teachers’ mathematical content knowledge, research on their numeracy capabilities is quite limited.

Via an online survey, an international dataset of practicing teachers’ views of numeracy, mathematics, and the relationship between the two was gathered by Forgasz, Leder, and Hall (2017). Participants were teachers from all grade levels teaching across all subject areas. Focusing on responses from teachers in Australia, the U.S., and Canada, it was found that many from each country could not articulate what numeracy was, nor did they...
appear to appreciate contemporary perspectives on the relationship between mathematics and numeracy.

Forgasz, Leder, Geiger, and Kalkhoven (2015) conducted an exploratory study with 151 prospective teachers and found that, despite being generally capable of answering a series of numeracy items suitable for 15-year-olds correctly, about 50% of the participants did not believe they had studied sufficient mathematics to be competent teachers. In an earlier study, Watson and Moritz (2002) required prospective teachers to select a newspaper article that included numerical data and develop a lesson idea based on the content. They concluded that such tasks were likely to assist teachers to help their students “become quantitatively literate citizens” (p. 55).

No studies were found in which the views and/or capabilities of sub-groups of prospective or practicing secondary teachers about numeracy were compared. The present study addresses this issue.

METHODOLOGY

This project, now in its fourth year, involves pre-service teachers enrolled in a required unit about the teaching and learning of numeracy in the Master of Teaching (MTeach) program at a prestigious Australian university, herein referred to as University X. At the start and end of the semester, students were asked to complete online questionnaires about numeracy. In this paper, we focus on the pre-unit questionnaires completed by students in 2017 and 2018. It is only in the pre-unit questionnaire that students were required to answer questions gauging their numeracy capabilities.

Data Collection Instrument

The pre-unit questionnaire, a modification of a questionnaire created by Forgasz et al. (2015), contained both closed and open-ended questions. The questionnaire began with demographic questions (e.g., age, gender). Next, there was a section about participants’ views of numeracy, mathematics, and teaching (e.g., relationship between mathematics and numeracy). The third section was comprised of six calculation questions, of which five were drawn from large-scale assessments of numeracy: the 2010 Year 9 NAPLAN test and the 2012 PISA test. After the participants completed each calculation question, they were asked to state their level of confidence in the accuracy of their response (i.e., right, wrong, unsure).

Here, we discuss the results from five items, of which three focused on the participants’ views. Specifically, we considered (1) whether the participants thought that there was a difference between mathematics and numeracy, (2) the participants’ views of their own mathematical ability, and (3) whether the participants thought that it is important for teachers to be good at mathematics. These three questions were all multiple-choice, with the response options “yes”, “no”, and “unsure” for the first and third questions. The second question had the following five response options: “weak”, “below average”, “average”, “good”, and “excellent”.

Additionally, two calculation questions (with associated confidence questions) were analysed for this paper. The first question (“Code Question”) required participants to calculate the total possible number of four-digit codes possible using a 10-digit (0-9) keypad. One example, 0051, was provided, as well as an image of a keypad. Participants typed their answers into a textbox. This question was selected because it had been previously found to have been answered poorly (Forgasz et al., 2017; Hall & Forgasz, 2017), and thus could be considered a difficult question. The second question (“Distance Question”) was selected because it was considered to be of medium difficulty, based on previous analyses. This
question required participants to select which distance (0.1203 km, 123 m, 1,230 cm, or 12,030 mm) was the longest, requiring an understanding of unit conversions.

**Participants**

There were 43 participants (2017: 33; 2018: 10) who identified themselves as secondary pre-service teachers and who answered questions beyond the demographic portion of the questionnaire. Most participants were women (67%) and students aged 25 and older (67%); this profile was reflective of the student population in the MTeach program generally. The students’ subject area specialisms were classified into STEM (e.g., chemistry, mathematics) and non-STEM (e.g., business, visual art) groups: 18 STEM (42%) and 25 non-STEM (58%) students. The STEM students were evenly divided by gender, while the non-STEM students were mostly women (80%). Unsurprisingly, the majority (78%) of the STEM students had studied tertiary level mathematics, compared to only 16% of the non-STEM students.

**Analyses**

The questionnaire data were analysed several ways. The three “views” questions were all multiple-choice questions, and the findings were initially analysed through descriptive statistics. The responses to the Achievement Level Question were quantified (1 = weak to 5 = excellent) so that quantitative analyses could be conducted. The responses to these questions were analysed through two-way ANOVAs to compare the mean scores of the STEM students and non-STEM students.

The Code Question was coded as right (answer of 10,000), wrong (incorrect numerical answer or a response like “lots”), or blank (no response or a response like “I literally have no idea”). The wrong answers were also analysed for any trends (e.g., multiples of 10). The Traffic Light Question was multiple-choice, so the responses were analysed similarly to those for the “views” questions. The responses to the associated questions about the participants’ confidence in their responses were analysed via cross-tabulations.

**RESULTS AND DISCUSSION**

In the following sections, we discuss the findings from our analysis of the three questions about the participants’ views of mathematics, numeracy, and teaching, as well as the two calculation questions (both the accuracy and confidence of the responses).

**Differences between Mathematics and Numeracy**

The majority of students (33: 77%) believed that there was a difference between mathematics and numeracy, compared to three (7.1%) who did not believe that there was a difference and six (14.2%) who were unsure. Of those who believed there was a difference, there was a higher proportion of STEM (88%: 15) than non-STEM (72%: 18) STEM students. Only non-STEM students did not believe that there was a difference. A slightly higher proportion of non-STEM (16%: 4) than STEM (11.8%: 2) was unsure. The differences in the distributions of responses were not statistically significant.

**Perceptions of Mathematical Ability**

The mean score for the question “How good are you at mathematics?” was 3.53 (1 = weak to 5 = excellent), indicating that, on average, the participants saw themselves as being between “average” and “good” at mathematics. There were no statistically significant differences in the mean scores of STEM and non-STEM students. However, the mean score of STEM students was higher than that of non-STEM students (3.71 compared to 3.39).
Perceptions of the Importance of Teachers Being Good at Mathematics

The participants were asked whether it was important for teachers to be good at mathematics. The results are shown in Table 1.

Table 1. Participants’ Perceptions of the Importance of Teachers Being Good at Mathematics

<table>
<thead>
<tr>
<th></th>
<th>STEM (n = 17)</th>
<th>Non-STEM (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is it important for</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>teachers to be good at</td>
<td>26 (63%)</td>
<td>4 (10%)</td>
</tr>
<tr>
<td>mathematics?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

While a majority of the participants agreed that it was important for teachers to be good at mathematics (63%), more STEM students (71%) than non-STEM students (58%) agreed. The reverse pattern held true for “unsure” responses, with more non-STEM students (33%) than stem students (17%) indicating uncertainty. However, the differences in the response patterns for the two groups were not statistically significant.

Numeracy Capabilities and Confidence

The STEM students’ and non-STEM students’ correct and incorrect responses to the two calculation questions and levels of confidence by subgroup who answered correctly and incorrectly are shown in Table 2.

Table 2. Comparisons between STEM and non-STEM Students on Two Calculation Questions

<table>
<thead>
<tr>
<th>Distance Question</th>
<th>STEM (n = 16)</th>
<th>Non-STEM (n = 23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>13 (81%)</td>
<td>3 (19%)</td>
</tr>
<tr>
<td>Confident correct?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>33%</td>
</tr>
</tbody>
</table>

For the Distance Question, similarly high proportions of STEM (81%) and non-STEM students (83%) were correct. However, of those who answered correctly, a higher proportion of STEM than non-STEM students was confident that their answers were correct (100% compared to 79%).

A higher proportion of non-STEM students (24.0%) than STEM students (16.7%) left the Code Question blank. The fact that this was not a multiple-choice question arguably contributed to this high rate of blank responses, as participants (a) may not have wanted to take the time to type a response or (b) may not have had any idea how to respond and could not simply randomly select from the provided responses. Of the participants who provided a response, nearly twice the proportion of STEM students (67%) than non-STEM students (37%) was correct. Interestingly, of those who were correct, all the non-STEM students, but only 80% of the STEM students, were confident that their answers were correct. This is the reverse pattern of confidence to the Distance Question. It may be the case that only the non-STEM students who were very confident about this topic attempted this question. For those
whose answers were incorrect, there was a similar pattern of the levels of confidence of answers provided for the STEM and non-STEM students. There were no patterns in the incorrect answers to the Code Question. Incorrect answers ranged from 8 to 40,000,000, and many seemed like complete guesses (e.g., “11107”, “1048576”).

CONCLUSIONS AND SIGNIFICANCE

In this paper, we compared the responses of two groups of secondary pre-service teachers – those with STEM specialisms and those with non-STEM specialisms – on a questionnaire about numeracy views, capabilities, and confidence. Compared to the non-STEM students, the STEM students tended to be more knowledgeable about numeracy, have more confidence in their own numeracy capabilities, and perform better on calculation questions; however, the differences between the groups were not statistically significant.

Nonetheless, it is important to pay heed to these differences, as they may be practically significant. The mandatory numeracy teaching and learning unit at University X plays an important role in assisting all pre-service teachers to develop a better understanding of numeracy, particularly its role in teaching. Recall that the findings presented here are from pre-unit questionnaires and, as such, reflect students’ views, confidence, and capabilities before engaging with unit materials. From our prior research (Authors, 2016, 2017), we know that the unit plays an important role in helping pre-service teachers to become more confident about their own numeracy capabilities and about incorporating numeracy in their teaching, as well as to be more knowledgeable about numeracy. Having increased confidence and understandings about numeracy will support teachers to address the requirements of the Australian Curriculum (ACARA, n.d.) and the Australian Professional Standards for Teachers (AITSL, 2017). An increase in confidence and knowledge about numeracy will support teachers to address the demands of an increasingly STEM-focused education.

REFERENCES


POLICY IMPLICATIONS OF THE NATIONAL NUMERACY TEST FOR INITIAL TEACHER EDUCATION: STUDENTS’ EXPERIENCES AND PERCEPTIONS

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ABSTRACT

In this paper, we consider how the externally-imposed policy requirement of passing the Literacy and Numeracy Test for Initial Teacher Education (LANTITE) before graduation impacts pre-service teachers’ experiences in their courses. We also explore pre-service teachers’ perceptions of the LANTITE. Data were collected through individual, semi-structured interviews with 12 pre-service teachers at a prestigious Australian university. Here, we focus on participants’ responses to questions about the introduction of the test, the impact of the test on their student experience, what they would do if they hadn’t passed the test, and suggested changes to the LANTITE. Whilst most participants were not positive about the introduction of the test or its impact on their student experience, there were some positive views provided. Some participants also provided suggestions for changes to the administration processes to reduce the negative impact of the test. The findings have implications for institutions providing teacher education programs regarding communications with pre-service teachers and policies for course progression linked to LANTITE outcomes.

Keywords: Numeracy, LANTITE, pre-service teachers

INTRODUCTION

Numeracy plays a crucial role in STEM teaching and learning. Applying mathematics in context, a fundamental idea in most definitions of numeracy (e.g., Australian Association of Mathematics Teachers, 1997; Goos, Geiger, & Dole, 2014), is necessary for undertaking STEM explorations and investigations, as science, technology, and engineering rely heavily on the application of mathematics. If teachers lack numeracy skills, they will struggle to develop such skills in their students and to incorporate numeracy in their teaching (Timms, Moyle, Weldon, & Mitchell, 2018). This will lead to a lack of confidence and capability to undertake rich STEM investigations.

In part due to concerns about teachers’ literacy and numeracy capabilities, the Australian Council for Educational Research (ACER) introduced the Literacy and Numeracy Test for Initial Teacher Education (LANTITE) in 2016. The policies that drove the LANTITE arose five years earlier, when the education ministers agreed to a national policy to accredit initial teacher education programs, particularly regarding pre-service teachers’ literacy and numeracy capabilities (ACER, n.d.). The Australian Institute for Teaching and School Leadership (AITSL) commissioned the development of the LANTITE to assess pre-service teachers’ literacy and numeracy capabilities (ACER, n.d.). Successfully completing the test indicates that the pre-service teachers are in the top 30% of the adult population in Australia with regard to personal literacy and numeracy (ACER, n.d.).
The introduction of the LANTITE, via external policy, had ramifications for universities that offer teacher preparation programs, as well as the students enrolled therein. Initially, the LANTITE needed to have been completed successfully by pre-service teachers before they could be registered to practice as teachers in Australia (Australian Government Department of Education and Training [AGDET], 2017). Now, as noted by ACER (2018), all students in initial teacher education courses need to pass the LANTITE prior to graduation. For instance, some universities require students to pass the LANTITE as part of the course entry requirements, whereas others require students to pass the LANTITE prior to their final practicum (ACER, 2018).

Here, we report on research conducted with pre-service teachers at a prestigious Australian university, herein referred to as University X, about their experiences with the LANTITE. In this paper, we draw on the interviews conducted with students enrolled in the university’s Bachelor of Education (BEd) and Master of Teaching (MTeach) programs.

**GOALS AND OBJECTIVES**

The goal of this paper is to explore how externally-imposed policy – namely, the requirement to pass the LANTITE in order to graduate from a teacher preparation program in Australia – affects pre-service teachers. Specifically, we focus on pre-service teachers’ perceptions of the test, as well as the impacts that the test has on their educational experiences and career plans.

**THEORETICAL FRAMEWORK**

The research project is framed by the 21st Century Numeracy Model (Goos et al., 2014), which is broadly aligned with a social constructivist epistemological stance. The model is provided in Figure 1.

Figure 1. 21st Century Numeracy Model (Goos et al., 2014).

As shown in the model, the “heart” of numeracy is the idea of applying mathematics in a context (citizenship, work, and personal/social life). In order to do so, people need a combination of mathematical knowledge, tools, and productive, positive dispositions. Underpinning the model is the is the idea of having a critical orientation. According to Goos
et al. (2014), numerate people “evaluate whether the results obtained make sense and are aware of appropriate and inappropriate uses of mathematical thinking to analyze situations and draw conclusions” (p. 85).

REVIEW OF LITERATURE

Introduced in mid-2016, the LANTITE is still relatively new, and there is limited literature available on the test. Most of the current literature focuses on the test’s purpose (e.g., ACER, 2016), potential issues (e.g., McGraw & Fish, 2017), analysis of the test itself (e.g., O’Keeffe, O’Halloran, Wignell, & Tan, 2017), or analysis of pre-service teacher performance on the test (e.g., Hall & Zmood, 2017). For example, McGraw and Fish (2017) suggested that “high stakes tests as gatekeeping devices are simplistic measures that fail to recognise important qualities of character crucial to effective teaching” (p. 1). As far as we are aware, our study is the first research on the LANTITE from the students’ perspective.

Several countries have implemented nationwide pre-service teacher literacy and numeracy assessments, and the U.K. Qualified Teacher Status (QTS) literacy and numeracy tests are similar to the LANTITE (U.K. Government, Department for Education [U.K. DfE], 2013). Again, most of the literature on the QTS tests focuses on the test’s purpose and potential issues (e.g., Hextall, Mahony, & Menter, 2001; Johnson, 2001). Time pressure, test anxiety, and mathematics anxiety are reoccurring themes (e.g., Johnson, 2001; Kay, n.d.).

Hextall et al. (2001) reported that students had negative feelings about the test’s existence and about completing the test. The link between passing the test and being a good teacher was questioned, particularly for prospective secondary teachers whose subjects involve minimal numeracy, such as English (Hextall et al., 2001; Johnson, 2001).

More generally, numerous “student experience” issues have been raised about standardised testing, particularly high-stakes and timed tests. The LANTITE, which is timed, is high stakes since pre-service teachers cannot graduate from their teacher preparation programs unless they meet the test’s standard. Due to the timed nature of standardised tests, students can experience pressure, stress, and anxiety (e.g., Boaler, 2014).

METHODOLOGY

The project involved online questionnaires and interviews with pre-service teachers enrolled in University X’s BEd and MTeach programs. Participants were recruited for the questionnaire portion through an announcement on the university’s LANTITE preparation Moodle site. Questionnaire participants were invited to volunteer for individual interviews to further discuss the LANTITE. The interviews were conducted by one of University X’s faculty members employed to support students with the LANTITE (herein referred to as “the interviewer”).

Data Collection Instrument

The semi-structured interview protocol consisted of questions about each participant’s background/demographic information, as well as her/his experiences with and views of the LANTITE. Parallel questions were provided about the literacy and numeracy components. Participants were also asked for feedback about University X’s LANTITE preparation resources.

Here, we focus on four interview questions that target students’ perceptions of the test and its impact on their studies and career paths: (1) thoughts about the introduction of the
test, (2) impact of the test on their student experience, (3) a discussion of what they would do if they hadn’t passed the test, and (4) suggested changes to the LANTITE testing process.

Participants

Transcripts were provided for 12 participants. All participants had passed the LANTITE and planned to teach in Australia. Summary data are provided in Table 1.

Table 1. Summary data about the participants.

<table>
<thead>
<tr>
<th>Participant Number</th>
<th>Age</th>
<th>Language Background</th>
<th>Course</th>
<th>Teaching Level</th>
<th>Specialisms</th>
<th>Year Level in Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39</td>
<td>German</td>
<td>MTeach</td>
<td>Secondary</td>
<td>German, Business management</td>
<td>2nd</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>Mandarin</td>
<td>BEd/BSc</td>
<td>Secondary</td>
<td>Mathematics, Science</td>
<td>1st</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>English</td>
<td>BEd</td>
<td>Primary</td>
<td>N/A</td>
<td>4th</td>
</tr>
<tr>
<td>4</td>
<td>31</td>
<td>English</td>
<td>MTeach</td>
<td>Primary/Secondary</td>
<td>Accounting</td>
<td>1st</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>Cantonese/Mandarin</td>
<td>BEd/BSc</td>
<td>Secondary</td>
<td>Biology, Chemistry</td>
<td>4th</td>
</tr>
<tr>
<td>6</td>
<td>21</td>
<td>English</td>
<td>BEd</td>
<td>Primary/Secondary</td>
<td>Inclusive education</td>
<td>3rd</td>
</tr>
<tr>
<td>7</td>
<td>23</td>
<td>English</td>
<td>MTeach</td>
<td>Primary</td>
<td>N/A</td>
<td>1st</td>
</tr>
<tr>
<td>8</td>
<td>35</td>
<td>English</td>
<td>MTeach</td>
<td>Primary</td>
<td>N/A</td>
<td>1st</td>
</tr>
<tr>
<td>9</td>
<td>18</td>
<td>Mandarin</td>
<td>BEd/BSc</td>
<td>Secondary</td>
<td>Biology, Chemistry</td>
<td>1st</td>
</tr>
<tr>
<td>10</td>
<td>23</td>
<td>English</td>
<td>BEd/BA</td>
<td>Primary</td>
<td>N/A</td>
<td>4th</td>
</tr>
<tr>
<td>11</td>
<td>21</td>
<td>English</td>
<td>BEd/BA</td>
<td>Secondary</td>
<td>English, English as an Additional Language</td>
<td>4th</td>
</tr>
<tr>
<td>12</td>
<td>38</td>
<td>English</td>
<td>MTeach</td>
<td>Primary/Secondary</td>
<td>Mathematics</td>
<td>1st</td>
</tr>
</tbody>
</table>

As shown in Table 1, most participants were in their 20s or 30s and had an English language background. Most of the participants with a specialism were in mathematics-related fields.

Analysis

The interviews were transcribed verbatim by a transcription company. The four selected questions were coded by the authors using emergent coding methods (Creswell, 2014). That is, all of the participants’ responses were read several times to get a sense of the data. Then, coding categories were created based on the reading of the data. The codes were then applied to the responses.
RESULTS AND DISCUSSION

In the following sections, we discuss the participants’ perceptions of the introduction of the LANTITE, as well as the ways in which it impacted their student experience. We also address how the participants would have responded if they had not passed the LANTITE. Finally, we discuss the participants’ suggestions for changes to the testing process. Due to the semi-structured nature of the interviews, not all participants were asked all of the questions by the interviewer.

Introduction of LANTITE

All participants shared their thoughts on the introduction of the LANTITE. Four students were positive about the test, with three feeling that the test would help raise the standards for teachers and another one feeling that it would “help boost the view of the profession of teaching” (P5). However, three participants felt that the test was not linked to being a good teacher or to actual classroom practice, whilst another participant said the test was not linked to the course, and yet another participant did not feel that the test effectively assessed knowledge. Regarding the test’s implementation, half the participants didn’t know about the test before enrolling in their course. Three of these participants were first-year students who could have found out through public information about teaching courses. However, for the other three participants, the requirement to complete the LANTITE was introduced when they were partway through their course. In terms of its personal impact, four participants said that the introduction of test made them feel nervous, anxious, and/or stressed. For instance, P10 said that she felt “anxious about the whole thing, really. Particularly the maths. Maths has never been my strength”. Notably, this stress was generalised, not simply when students were preparing for or completing the LANTITE.

Impact on Student Experience

Nine participants were asked what impact the LANTITE had on their student experience. Of these, three participants suggested that it had a positive impact, with one participant saying that the practice helped build her numeracy skills. One participant said that the test didn’t have much of an impact except for a few weeks, presumably those weeks leading up to the test. Five participants suggested that the LANTITE had a negative impact, with the most common response (n = 4) being that having to do the test was annoying and added pressure by having another thing to worry about, especially if they didn’t pass.

For instance, P7 said, “The whole build up of it, having to go to a test centre in [city], having the pressure… if you don't pass it the first time around”. The last participant raised the issue that the test contradicted what she was learning about the best way to teach so that students learn and she was frustrated at not getting more detailed feedback on her test performance.

If They Hadn’t Passed

Ten participants were asked what they would have done if they hadn’t passed the LANTITE. The most common response (n =5) was that they would do additional preparation. Some participants suggested that they would use more “intense” types of preparation, like meeting with the university’s literacy and numeracy support staff or attending workshops (compared to just completing online tests, for instance). The second most common response was that the participants would re-take the test (n = 4).

Two participants reported that they would experience emotional distress if they had failed the test while, more concerningly, three participants reported that they would reconsider their career choice. For instance, P8 said, “I probably wouldn’t continue with the
course”. Such responses provide evidence of the value that students place on the test as an accurate indication of their capabilities as teachers.

**Suggestions for Changes to the Testing Process**

Ten participants were asked to suggest changes to the LANTITE testing process. The most common answer ($n = 7$) was to change the timing of the test windows. The participants found it difficult to complete the LANTITE while they were busy with assignments or teaching placements. Other common suggestions related to the test location ($n = 5$) and the cost ($n = 5$). In-person tests had to be completed in the city centre, which was not conveniently located to the campus.

For instance, P1 shared that “travelling to the city is not my favourite thing to do. That always stresses me out a little bit” – stress that certainly is not needed on an already stressful testing day. The participants felt that the cost was a “cash grab” and suggested that it could be prohibitive for some students: “As uni students, we don't have $200 lying around, so it was quite a hit to the bank account that day. So, for me, it was just more disappointing that it’s been made compulsory for us by some higher body” (P6). Other suggestions related to the booking process and the feedback provided.

**CONCLUSION AND SIGNIFICANCE**

Stress, anxiety, and negative emotions were common themes discussed by the participants. Issues related to the timing, location, and cost of the LANTITE exacerbated these feelings. The high-stakes nature of the test meant that some participants would reconsider their career path if they had failed, while others would do more preparation and re-take the test.

More effective communication from universities to pre-service teachers would increase their understanding of the test processes and may help to alleviate some of the stresses discussed above. Specifically, if the students were more aware of the test requirements, they could complete the LANTITE in the February test window, before the commencement of their university studies. Doing so would alleviate the challenges of balancing LANTITE preparation with the demands of assignments and teaching placements.

This externally-imposed test creates ethical and practical issues for universities, particularly in terms of course progression. Since the policy regarding successful LANTITE completion has changed from a registration requirement to a graduation requirement, universities are grappling with their internal policies regarding when students need to complete the LANTITE. Requiring students to complete the LANTITE in the first year of their course ensures that students are not spending multiple years and thousands of dollars in a course for a profession that they will never be able to practice. As discussed earlier, teaching is a profession that is becoming increasingly STEM-focused and, consequently, teachers need to demonstrate that they have the necessary level of numeracy skills to support such teaching and learning.

**REFERENCES**


PIVOTS, PROFESSIONAL VISION, AND REFLECTIVE DESIGN IN PUBLIC COMPUTING

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ABSTRACT

Public computation has recently been proposed as a new form of open-ended, public learning environments, typically designed in public spaces such as walkways or museums, where visitors (anyone) can directly access, modify and create complex and authentic scientific work through interacting with open source computing platforms. However, such ill-structured spaces exist in ways that do not provide easy opportunities for assessment of learning. This paper attempts to illustrate how we can productively analyse collaborative learning between professional students in such a setting, located in a public walkaway in a large Canadian public research University. We analyse the conversations and interactions between two pairs of university students who are also experienced professionals (both in STEM and non-STEM disciplines), as they attempt to modify the underlying, open source code of simulations of complex systems in a public computing environment. While previous research has illustrated how pivots and figured worlds (Holland, Lachicotte Jr., Skinner, & Cain, 1998; Vygostky, 1978) shape visitors’ experiences of public computation, our analysis further reveals the roles that professional vision (Goodwin, 1994) and reflective design (Schön, 1983) play in the experience of the visitors. More broadly, our study has implications for the analysis of learning in public and informal spaces for STEM education where visitors range from young learners to experienced professionals, which can in turn help us understand how STEM can become a truly more public experience. We illustrate how identity work in the form of constructing figured worlds though the lens of professional vision can help us understand experienced professionals’ ways of sense-making in public computing environments.

Keywords: Public computing, public computing, computational thinking, professional vision, reflective design, pivots, figured worlds
INTRODUCTION

“Public computing” was first introduced by Sengupta and Shanahan (2017) as “a new form of open-ended, public learning environments, in which visitors can directly access, modify and create complex and authentic scientific work through interacting with open source computing platforms” (p. 1124). They designed the DigiPlay learning environment as a way to engage individuals with open-source simulations of emergent behavior (Sengupta & Shanahan, 2017). They suggest that public learning environments can help bring together both participants and designers in computing (Sengupta & Shanahan, 2017).

By using a programming language that is under an open-source license and displaying that code out in the open, individuals can interact with and “hack” the code to provide a deeper understanding of how these simulations are programmed and designed.

However, the ill-structured nature of such spaces can present a challenge for the analysis and assessment of visitor experiences and learning. This paper extends previous research on analysis of learning in public computing environments by highlighting how the epistemological constructs of professional vision (Goodwin, 1994) and reflective design (Schön, 1983), in addition to previously identified constructs such as pivots and figured worlds (Holland et al., 1998; Vygotsky, 1978) can be used productively to help us understand how collaborative learning between professional students takes place in such settings.

THEORETICAL BACKGROUND

Figured Worlds, Boundary Play and Pivots

Sengupta and Shanahan (2017) have argued how public coding, figured worlds, boundary play, and boundary work are intertwined and constitute the experience of public computation. A figured world is a “socially and culturally constructed realm of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others” (Holland et al., 1998, p. 52).

Participants in these worlds create shared values, norms, and rules (Holland et al., 1998). School science is a type of figured world where students and teachers are constantly redefining ideas of what science is and who can be a part of it (Carlone, Haun-Frank, & Webb, 2011). If our identities are incongruent with our ideas of who “belongs” in the figured worlds of science and coding, it can create barriers and make it difficult for us to work with science and coding in meaningful ways.

The idea of a “pivot” comes from Vygotsky and is further elaborated upon by Holland et al. (1998). Pivots can help individual enter into new figured worlds, and can be through dialogue or material artifacts (Holland et al., 1998). “Pivoting” can help individuals remake and redefine their figured worlds to be worlds in which they feel more comfortable and welcome.

Playing with the code underlying the simulations can be considered “boundary play” in which individuals can cross boundaries into different figured worlds and remake these figured worlds in their minds (Sengupta & Shanahan, 2017). Sengupta and Shanahan (2017) also found that changes in the code can act as “pivots” into new figured worlds.

For example, a young child creating a “Boid prison” by modifying the code pivots him into a figured world in which he can create and hack code (Sengupta & Shanahan, 2017). Similarly, a student who has learned about the large universe model in an Astronomy class can see its connection the Boid simulation, which again acts as a pivot into the new figured
world in which she has become a coder and changed the simulation (Sengupta & Shanahan, 2017).

Professional Vision

Goodwin (1994) defined professional vision as “[consisting] of socially organized ways of seeing and understanding events that are answerable to the distinctive interests of a particular social group” (p. 606). Members of a social group or profession have different ways of viewing events and making meaning of phenomena, informed by their professional knowledge and skills. Goodwin (1994) discussed three practices which can build professional vision: coding, highlighting, and producing and articulating material representations.

Coding involves transforming and categorising phenomena in order to make them relevant to the profession (Goodwin, 1994). Codes provide a way for professionals to analyse and discuss phenomena, and this systematic method of coding can also be used to foster a form of professional vision in non-professionals. The second practice Goodwin discussed was highlighting. Highlighting is used “so that events relevant to the activity of the moment stand out” (Goodwin, 1994, p. 610), or to mark important features. Finally, the third practice is the use of graphic representations, as experts use not only linguistic text to describe their work, but also diagrams, photographs, and graphs.

Reflection-In-Action

Schön (1983) introduced the notion of design as a reflective conversation with the situation. In this view, designers ask “what if?” questions, and consider the implications of their design choices from multiple perspectives. He defined knowing-in-action as the indescribable feelings and unconscious knowledge that causes a practitioner to do something a certain way because it “feels right” (Schön, 1983). This knowing-in-action often comes through experience.

Reflection-in-action involves noticing different aspects of the situation, thinking about how to make decisions, recalling procedures, and framing situations in a certain way (Schön, 1983). This leads to reflection-in-practice, where professionals go about their practice and often encounter new cases. They learn from these new cases by reflecting on their previous experience, and use that experience to make decisions about how to proceed (Schön, 1983).

In some cases, this professional knowledge becomes so ingrained that professionals don’t even realise that they are using what they’ve learned in previous experience to solve a new problem; it just feels like the right thing to do, which relates back to knowing-in-action.

RESEARCH DESIGN

The Setting: DigiPlay

The study was conducted in the DigiPlay learning environment designed by Sengupta and Shanahan (2017), which consists of three 80” touch screens in an indoor, public walkway at the University of Calgary. On the screens are simulated visualisations of flocking, where “Boids”, i.e., virtual agents that are programmed to act like birds, move intermittently in emergent patterns (flocks) (Sengupta & Shanahan, 2017).

The patterns (flocks) are emergent because the flocks emerge as a result of simple interactions between the Boids: avoidance, cohesion and alignment. These simulations are coded using Processing, an open-source programming language, which has many powerful tools for visualisations and is used by professional programmers, computer scientists as well as digital artists (Reas & Fry, 2007).
There were two main simulations used for the purpose of this analysis, both shown in Figure 1. The first is a flocking simulation, in which Boids show emergent flocking behaviour through rules controlling their avoidance, approach, and alignment to each other. The second simulation builds upon the first by incorporating stationary obstacles; Boids still flock according to the previous rules, but users can also change how much the Boids (green) try to avoid the stationary obstacles (blue).

![Figure 1. Two simulations from the DigiPlay exhibit: flocking (left), and flocking with obstacles (right)](image)

**Data**

Data was collected through video recordings of two pairs of university students: Peter and Avery, and Jess and Ann. Peter, Avery, and Jess are graduate students in education, and Ann is a PhD student in electrical and computer engineering. Both Peter and Ann have previous experience in programming through undergraduate degrees in computer science (Peter), and bachelors and master’s degrees in computer and electrical engineering (Ann).

In the video recordings (15-30 minutes in length), participants were encouraged to explore the DigiPlay exhibit, but were given no other instructions. As the recorder and researcher, I (the first author) occasionally interacted with the participants to provide some clarifying information about the programming language, or to point out an observation that had not been articulated by the participants. The video recordings captured what the participants said, their physical interactions with the screens, and the screen itself to include any code changes.

**Analysis**

Following Sengupta & Shanahan (2017), we adopted a phenomenographic approach for our analysis. Our choice of phenomenography was grounded in the argument from Marton that phenomenography deals with the forms of immediate experience, conceptual thought, and physical behavior (Marton, 1986).

This is particularly important for our theoretical focus on professional vision, reflection-in-action and figured worlds, which as Sengupta & Shanahan (2017) pointed out, “involves not only how we act in the world, but also how we conceptualize and interpret our actions and the environment where we are and might be situated” (p. 1129).

Our analysis is thematic in nature. We rely on observations of the visitors’ actions and conversations, facilitated by the recordings and field notes, as our primary source of data. To
look for instances of boundary work and boundary play, we focused on the actions the
visitors undertake in DigiPlay as they alter the visualisations and the code.

FINDINGS

Figured Worlds and Pivots

One of the most significant events in Jess’s and Ann’s interactions with the DigiPlay
exhibit came after they had explored the Boid behaviour in the simulation and began to look
through the code. As Ann was scrolling through the code to find the algorithm determining
the Boids’ behaviour, she remarked “this is risky, what if I modify the code?”, to which Jess
replied, “[the designer] wants you to modify the code”. Ann was immediately very excited at
the prospect of changing the code, and for the rest of the session their interactions with the
exhibit involved changing the code and determining the impact their changes had.

This moment represents a pivot from one figured world to another. In one figured
world, she was interacting with electronic artwork, and was operating under the assumptions
that the art/code could be enjoyed, but not changed, even though she had the skills and
experience in order to do so. She was also participating in the figured worlds of a research
participant and a friend; she wanted to help the researcher collect appropriate data for the
class, and she admitted after the session that since she wasn’t given much direction, she was
hesitant to do something that would “mess up” the data collection.

Jess telling her that she was free to modify the code caused Ann to pivot into the
figured world of programming and design. In this new figured world, the open-ness of coding
meant that making changes to the code was acceptable and even encouraged. This pivot
erased her apprehension at modifying the code and paved the way for her and Jess to make
changes to parts of the code that could be considered “critical” to the exhibit, such as the
flocking algorithm.

Professional Vision

In both pairs of participants, there was one individual who could be considered an
“expert” or a professional in the discipline of computer programming through their
educational background. For these individuals, highlighting (Goodwin, 1994) was evident in
the way that they “read” and discussed the source code for the simulations. Peter was
skimming the code by reading aloud the code in segments or “chunks”, rather than looking
line-by-line. As he was doing so, he was also verbally identifying the different data
structures, such as static variables, location vectors, forces, and constructors, that are
particular ways of organizing and storing data that are commonly used in programming
languages. This was evident, for example, in his explanation of how several lines of code
together made up the “constructor” for the Boid.

In object-oriented programming (the form of programming used in the simulations), a
constructor is a form of sub-routine (i.e., a chunk of code) that is specifically designed to
create a computational object. Peter’s use of formal knowledge from the domain of his
professional practice - computer programming - is evidence of his professional vision at work
in his interpretive experience at DigiPlay.

Peter used another professional code throughout the transcript when he talked about
something being “a bug” or “buggy”. A program is said to have a bug if it does not work
properly. Peter felt that the switch to toggle the background colour from white to black was
“buggy” because you had to hit the button a couple of times to make the colour switch, rather
than just once. When he spotted the switch statement with the missing case 2 (shown in
Figure 2), he talked through how the switch statement works programmatically in order to explain it to Avery.

As he was talking, he remarked that “actually, that would be a bug”, referring not only to the missing case for 2, but the fact that case 3 could never be reached in the program. Peter’s use of the code “bug” for these errors in the programming code shows that he believed the program was not working as the original programmer intended, and was drawing attention to this discrepancy between planned and actual behaviour.

![Figure 2. Peter used professional vision to point out the "bug" of case 2 being empty](image)

Ann also used the practice of highlighting once she began to look through the source files of the code. As someone who was interested in understanding the flocking behaviour of birds, she was attempting to find the algorithm in the code. Similar to Peter, she used her professional vision to skim quickly through the code by scrolling up and down the screen (see Figure 3), and was able to determine within a few minutes where the algorithm was located in the code.

Her professional vision was evident in her search, for example, when she realised that she had scrolled down on the touchscreen “too far” and said “no we’re just… setting up the sliders and stuff. Okay nope, this is all just making it look nice” before moving on to a different source file.

Here Ann was able to identify the purpose of the code (“setting up the sliders”; “making it look nice”). Ann was not only familiar with programming, but also with the specific programming language used in this exhibit. This allowed her to distinguish between what she viewed to be important (the flocking algorithm) from what she felt was unimportant (setting up the graphical interface).

![Figure 3. Ann used professional vision to find the code that she deemed to be more important: the Boid flocking behaviour](image)
Reflection-in-action

The participants also showed evidence of reflecting-in-action. Peter and Avery added another case into the switch statement that determines the colour of the Boids. They used an RGB value of (100,100,0), which works out to a brown-yellow colour. They did not look up what that colour would be, and then when they ran the code, they were unable to determine which shades of colour had been there before, and which were new. At that point, Avery remarked “I guess we should’ve looked at what colours we were getting before we added [the new line of code]”.

This reflection led them back to the code, where they took a different approach to see if their line of code was working, using the console to print a message if it reached that case. It is interesting that the reflection of “we should’ve seen what was happening before” did not cause them to reverse their change in the code, but to instead find a different method of determining if their code was working. This new interaction with the code may not have occurred without this reflection.

Similar reflecting-in-action was evident the work by Ann and Jess. They decided to add a multiplier to the flocking force calculation in an attempt to change how the Boids aligned together. At first, they just multiplied by 10. After studying the simulation after the change for a few seconds, Ann wondered, “maybe we didn’t make a significant change” and Jess agreed, “maybe we didn’t”. At first, Ann suggested changing it back, but then quickly changed her mind and said, “or you know what, let’s make it 100 and then go back. Do three scenarios”. After changing the multiplier to 100, there was a noticeable change in the simulation; Boids were trying to align much more strongly, to the extent that some were “getting caught up there” according to Jess, seen in Figure 4.

![Figure 4. Jess pointed out that the Boids were getting caught](image)

The behaviour was different than before, and more reflection-in-practice took place when Ann reasoned, “I wonder if 10 just wasn’t enough of a difference. I wonder what 1000 would do”. Changing the value to 1000 further strengthened the alignment and helped Ann and Jess see more clearly the effect of changing that value on the Boids’ behaviour.

CONCLUSIONS

Overall, while previous research has illustrated how pivots and figured worlds shape visitors’ experiences of public computation (Sengupta & Shanahan, 2017), our analysis further reveals the roles that professional vision (Goodwin, 1994) and reflective design
(Schön, 1983) play in the experience of the visitors. Getting “permission” to change the code in a simulation can trigger a pivot from figured worlds of art and research into the figured world of programmer, leading to different experimentation with the simulation code.

Professional vision was useful for participants to highlight parts of code they believed to be most important, and to spot potential “bugs” which could then form the basis for inquiry. Finally, interactions with the simulation can be considered in terms of reflection-in-action: wondering what would happen if a change was made, making that change, and determining the results. These frameworks together provide a productive context for playful exploration of the simulations and the underlying code.

More broadly, our study has implications for the analysis of learning science and computing in public and informal spaces for STEM education where visitors range from young learners to experienced professionals, which in turn can help us understand how STEM can become a truly more public experience.

Within this broader scope, the current paper illustrates how identity work in the form of constructing figured worlds though the lens of professional vision can help us understand experienced professionals’ ways of sense-making in public computing environments.

REFERENCES


ABSTRACT

The Australian Curriculum: Digital Technologies provides an opportunity for teachers to integrate coding and computational thinking within their STEM teaching practices. However, this opportunity has proven to be a challenge for many teachers, as their self-efficacy with respect to teaching these new skills is often low. This research explores the implementation of a professional development program that focussed on the integration of coding and computational thinking within the teaching of mathematics in primary school classrooms. In particular, we study changes in teacher self-efficacy with regards to coding and computational thinking before and after participating in the program. Using the validated Teachers’ Self-Efficacy in Computational Thinking (TSECT) instrument as well as focus group data, we analyse the experiences of 15 primary school teachers in New South Wales, Australia. We conclude that the program, based on the ScratchMaths resources developed in the UK, was successful in improving teachers’ self-efficacy towards both computational thinking and the integration of mathematics and coding. Our qualitative analysis of the focus group conversations also highlighted teachers’ positive perceptions of student engagement and the need to make the mathematics concepts underpinning the ScratchMaths modules more explicit.

Keywords: Teacher professional development, computational thinking, integration of coding and mathematics in STEM.

GOALS AND OBJECTIVES

Computer programming has been utilised as a pedagogical tool to facilitate understanding of mathematical concepts since computer languages were made widely available through personal computers. Early examples of using computer programming to explore mathematics concepts through the process of ‘testing and debugging’ are found in the literature as early as the 1960s (Feurzeig, 1969), although perhaps the most salient case of advocacy for this pedagogical approach has been the one proposed by Seymour Papert.

Papert, a mathematician, posited that young people learn best when they are engaged in the construction of digital and/or physical artefacts that are personally meaningful to them and that can be shared with others (Papert, 1980). During the late 1980s, personal computers were introduced in schools in the United States of America (USA) and the United Kingdom (UK), which, in turn, allowed for the teaching of programming languages in mainstream K-
12 education (Agalianos, Whitty, & Noss, 2006). The use of Papert’s ideas, including their integration into mathematics classrooms, has been the object of notable studies since that time (Benton, Hoyles, Kalas, & Noss, 2017; Hoyles & Noss, 1992; Kafai & Burke, 2015; Kafai & Harel, 1991; Wilensky & Resnick, 1999).

Many countries, such as the UK, the USA and New Zealand, have recently introduced STEM curricula in compulsory and post-compulsory schooling, and there is often a focus on teaching coding and computational thinking within STEM (Bell, Newton, Andreade, & Robins, 2012; Brown, Sentance, Crick, & Humphreys, 2014; Fisher, 2016). However, introducing coding and computational thinking into compulsory education undoubtedly presents challenges for teachers, as the learning of these skills has not usually been part of their formal education. This is particularly true for primary school teachers, as they are unlikely to have completed a technology major at university, are usually generalist teachers, and often possess low levels of self-efficacy in relation to coding and computational thinking (Bean, Weese, Feldhausen & Bell, 2015).

Interestingly, one of the approaches suggested for helping prepare teachers for teaching coding and computational thinking is to integrate them into the STEM subjects they are currently teaching, for example, mathematics (Barr & Stephenson, 2011). This approach to teacher professional development constitutes the essence of the ScratchMaths project, led by Hoyles and Noss (Benton et al., 2017), currently underway in the UK, designed to help prepare primary school teachers undertake the challenging task of bringing the new digital technologies curriculum in an integrated manner to their classrooms.

This paper reports on a pilot project centred on adapting ScratchMaths materials to the Australian mathematics and digital technologies curricula and exploring its implementation with 15 primary school teachers in the State of New South Wales (NSW), Australia. Our research questions are:

- Does participant teachers’ self-efficacy with regards to coding and computational thinking increase after learning and using the adapted ScratchMaths resources?
- Does their self-efficacy with regards to using coding to teach mathematics also increase?

STUDY DESIGN

ScratchMaths is a project that incorporates the programming language Scratch. Scratch is a visual programming language designed for introducing students to computing, which was developed at MIT Media Lab (Resnick et al., 2009). Scratch is used widely by Australian primary school teachers as a way to introduce coding in their classroom, and its pedagogical possibilities in mathematics in Australian schools are currently being explored (Miller & Larkin, 2017).

ScratchMaths is a two-year computing and mathematics-based curriculum for Key Stage 2 in the UK (equivalent to Years 4 and 5 in Australia). Its aim is to enable students to engage with and explore important mathematical ideas through coding in Scratch. The ScratchMaths curriculum contains 6 modules of work and incorporates teacher guides, classroom presentations, Scratch starter projects, additional challenges and reference posters.

For the Australian pilot project reported in this paper, we conducted professional development in ScratchMaths with Stage 3 (Year 5 and 6) teachers. The pilot project ran for roughly 8 weeks, commencing with a 2-day professional development workshop and ending with a final showcase where teachers shared their experiences and samples of students’ work. We also offered support during the interim classroom implementation period. The aim of the
pilot project was to explore participant teachers’ perceptions of their ability to facilitate students’ learning processes to develop mathematical ideas through coding, and how those perceptions varied after an eight-week intervention.

The concepts covered in the workshops included sequencing and repetition (loops), which are present in the Australian Digital Technologies curriculum (Australian Curriculum and Reporting Authority [ACARA], 2017) and have been identified in the literature as essential computational thinking concepts for students in the later stages of K-6 education (Brennan & Resnick, 2012; Rich, Strickland, Binkowski, Moran, & Franklin, 2017).

The ScratchMaths investigations used in the workshops introduce or reinforce a couple of computational and mathematical concepts and often build on concepts introduced in the preceding investigations. In Figure 1, an example of a stack of Scratch blocks from ScratchMaths is shown next to the tile pattern that results from these blocks being followed. This example includes some of the computational and mathematical concepts present in the investigations.

![Scratch blocks and tile pattern](image)

**Figure 1. A stack of Scratch blocks and the resulting tile pattern**

**METHODOLOGY**

To evaluate the effectiveness of our adapted resources, we used Social Cognitive Theory and its concept of self-efficacy (Bandura, 1993). Our choice was based on our belief that for teachers to embrace new concepts and pedagogies, they need to feel a certain amount of confidence in their ability to impart these concepts and utilise the pedagogies. In order to evaluate the change in teachers’ self-efficacy, we utilised the Teachers’ Self-Efficacy in Computational Thinking (TSECT) instrument.

This instrument was developed by Bean et al. (2015) to evaluate very similar initiatives, contains nine items, and has a high reliability (Chronbach’s Alpha = 0.935). Out of these nine questions, we used only seven, as two of the original items relate to US Common Core Standards and are irrelevant in the Australian context. We measured teachers’ perception of their ability to facilitate their students’ development of mathematical ideas using coding, using three validated questions from the ScratchMaths research project in the UK. All items are shown in Table 1.

Research data was collected via two main methods. We conducted pre- (n=15) and post- (n=8) intervention surveys linked through an identifier. The eight teachers who completed the post-intervention survey had also completed it prior to the commencement of the project. The surveys contained a range of Likert items as described above.

We aggregated each of the two scales into two variables by calculating mean scores. These mean scores were considered non-categorical variables for analysis purposes. A small number of open-ended questions were included in the surveys. These open-ended questions asked about the methods of integration of mathematics and coding that participant teachers
were already employing. Questions were also asked about the use of digital technologies for teaching mathematics.

The workshops were conducted in two different locations in NSW. Participating teachers came from a range of regional and metropolitan schools and across school sectors. Four teachers attended the 2-day workshop in the regional location, and eleven in the metropolitan location. Participating teachers were mostly female (n = 11) and their years of teaching experience ranged from less than 5 years to over 20. The schools where they taught were within the public and Catholic systems and had students with a very wide range of socioeconomic backgrounds.

At the end of the school term we invited the teachers to showcase their students’ work at each of the two project locations. After each of the showcases, we conducted two focus group interviews. The total number of teachers participating in the focus groups was six: two in the regional location and four in the metropolitan location. Both focus groups were audio-recorded and approximately one hour in duration. Questions focused on teachers’ experience teaching coding, computational thinking and mathematics; pedagogies preferred for teaching in these areas; professional learning to date; and details on their implementation of ScratchMaths.

RESULTS AND DISCUSSION

We observed gains in participants’ confidence with teaching across both areas (see Table 1). All items were presented in a 5-point scale from Strongly Disagree (coded as 1) to Strongly Agree (coded as 5). In terms of statistical significance, a paired-samples t-test was conducted to compare teachers’ perceptions prior to attending the workshop and after attending (n = 8).

There was a change in teachers’ perceptions of their ability to teach mathematics with programming before (M = 3.3, SD = 0.47) and after the intervention (M = 4.5, SD = 0.08); t = -5.09, p = 0.037. There was also a statistically significant difference in their self-efficacy with regards to coding and computational thinking before (M = 3.2, SD = 0.78) and after the intervention (M = 4.3, SD = 0.23); t = -5.05, p = 0.002.

Table 1. Pre- and post-survey results (items in Mathematics scale preceded by an asterisk)

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre</th>
<th>Post</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>I feel confident using simple programs for the computer.</td>
<td>4.60</td>
<td>4.71</td>
<td>0.11</td>
</tr>
<tr>
<td>I know how to teach programming concepts effectively.</td>
<td>2.67</td>
<td>4.14</td>
<td>1.48</td>
</tr>
<tr>
<td>I can promote a positive attitude towards programming in my students.</td>
<td>4.13</td>
<td>4.57</td>
<td>0.44</td>
</tr>
<tr>
<td>I can guide students in using programming as a tool while we explore other topics.</td>
<td>2.93</td>
<td>4.43</td>
<td>1.50</td>
</tr>
<tr>
<td>*I can guide students in using mathematical thinking as a tool when programming.</td>
<td>3.13</td>
<td>4.43</td>
<td>1.30</td>
</tr>
<tr>
<td>I feel confident using programming as an instructional tool within my classroom.</td>
<td>2.67</td>
<td>4.17</td>
<td>1.50</td>
</tr>
<tr>
<td>I can adapt lesson plans to incorporate programming as an instructional tool.</td>
<td>2.93</td>
<td>4.29</td>
<td>1.35</td>
</tr>
</tbody>
</table>
I can create original lesson plans, which incorporate programming as an instructional tool.  2.87  4.14  1.28

*I understand how mathematics concepts relate to programming concepts.  3.00  4.43  1.43

*I appreciate the value of teaching mathematics and programming in an integrated manner.  3.87  4.57  0.70

After attending the professional development workshops, teachers trialled the resources with their students over a period of up to eight weeks. In the follow-up showcase and focus group sessions with teachers, they all expressed positive sentiments about ScratchMaths. Teachers presented student work samples, including students’ reflective comments on ScratchMaths and unanimously reported that the students were engaged in learning and looked forward to the ScratchMaths sessions each week. They also elaborated how the resources were very well scaffolded and facilitated collaboration and social support for learning.

With regards to our research questions, participant teachers reported an increased level of self-efficacy with mathematics and coding. One teacher reflected: “mathematics has always been my area of weakness, as a kid I had enormous anxiety in maths [but I could use the resources because] it was very practical and made the 2D shapes understandable”. Another teacher, who had a high level of self-efficacy from the commencement of the project, said “maths is probably my favourite, I drive kids crazy ‘cos there’s no downtime in maths classes [but] with coding you don’t know everything and the [resources were] prepared so you could go back to the classroom and feel supported”.

Regarding the integration of mathematics and coding, teachers reflected that while there was strong evidence for sustained student engagement with ScratchMaths, not all students were actively engaged with the mathematical concepts underpinning the activities. When this issue was discussed in the focus groups, the teachers agreed that the mathematical aspects of the activities were not adequately understood by all students, and that in future they need to be more explicit in directing students to engage with the mathematical components of the module.

In the focus group conducted in the regional location one of the teachers commented “the maths was a lesser learning outcome than the coding for us”, and the other responded, “yes, some of them didn’t quite get the concepts. In the beginning some of them didn’t get that they could do [360 degrees using a loop], so there was a lot of repetitions”. In the focus group in the metropolitan area, teachers commented that in many cases students were taking a ‘trial and error’ approach to completing the patterns involved in the module, rather than working through their solutions mathematically. They all agreed, however, that the activities were “a good practical way to reinforce concepts” already taught.

**CONCLUSIONS AND SIGNIFICANCE OF THE STUDY**

Many argue that the term ‘computational thinking’ popularised by Jeannette Wing a decade ago (Wing, 2006) is in no way different to logical thinking, a pedagogical construct that is inherent in mathematics education (Grover & Pea, 2013). Thus, it would seem that coding and mathematics are interlinked through shared conceptual ideas and therefore lend themselves to an integrated pedagogical approach. In this pilot study we found that participant teachers’ self-efficacy in relation to integrating mathematics and coding improved significantly after a relatively short period of engagement with ScratchMaths.
While this is a pilot project and the results on self-efficacy are not generalisable, the observations made by participants have implications for future ScratchMaths professional development sessions. Most of the participating teachers were coding novices, but through the professional development sessions they readily learned the basics of coding and were able to teach these skills to their students. However, for future professional development sessions, more emphasis needs to be placed on the mathematical skills underpinning the ScratchMaths modules and the pedagogical approaches that can be used to balance the mathematics and coding content. We intend to modify the professional development we provided in this pilot project to address the issues outlined above in order to continue our evaluation of ScratchMaths in the context of a larger scale project.

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BEAUTIFUL PHYSICS: RE-VISION OF AESTHETIC FEATURES OF SCIENCE THROUGH THE LITERATURE REVIEW

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ABSTRACT

This study intends to reveal the aesthetic features of physics through the literature review and to give some implications for teaching the beauty of physics. Among the papers published in the internationally prominent journals, indexed in SCI, SSCI, and A&HCI, this study selects a total of 88 articles dealing with aesthetics of physics, and categorises the aesthetics of physics into intrinsic and extrinsic representation of the aesthetics. As a result, simplicity, symmetry, harmony, and unity, centering on mathematical formalism, are found as the intrinsic aspects of aesthetics, whereas elegance, wonder and sublimity are mentioned as the extrinsic aspects of the aesthetics, which were evoked from the intrinsic aesthetics above. In terms of ontological and epistemological nature of aesthetics, modern physics does not give a clear answer about the simplicity of nature due to the indeterminacy, and the aesthetic judgment is linked to both intrinsic nature of an object and extrinsic sense of human mind, and finally aesthetic evaluation is determined by empirical worth of aesthetics and shared meaning of aesthetic attitude. Thus, this study gives some implications for the use of visual image in physics and teaching aesthetics of physics.

Keywords: Aesthetics, beauty, nature of science, physics education, literature review

GOALS AND OBJECTIVES

It is assumed in physics that there is a kind of simple and beautiful rule to satisfy the complex nature. Many scientists in the modern times also postulated aesthetic features of science (Miller, 2000). In addition, there are similarities between science and art (Vitz & Glimcer, 1984). The relationship between science and art is reciprocal by using images for visualisation or analogous thinking between the two. This indicates that ingenuity of physics is, to some extent, linked to aesthetics of physics. Thus, this study aims at synthesising aesthetic features of physics and giving some clues to resolve the aforementioned clashes through the literature review.

Especially, this study deals with three controversial issues about aesthetics in science. The first one is the distinction between aesthetics of nature and theories. Even though scientific theories are aesthetic, it is uncertain about the existence of aesthetics of nature. In other words, aesthetics is an outcome of scientific theories but nature itself is complex and has no support about elegance and beauty. Second, aesthetic induction suffers from anomalies and theoretical inconsistencies and propose a model free from such problems.

The aesthetic preference may fail to select appropriate explanation of the natural world. Aesthetic evaluation of scientific theories is very common and constitutes a perplexing intrusion of the irrational into science. Third, aesthetics of science entails subjective dimensions such as emotion and attitude, and it is impossible to clarify aesthetics of science.
Even, what can be taken into account as aesthetics of science is various and subjective, and there would be no certain criterion for aesthetic evaluation.

**THEORETICAL FRAMEWORK**

As for the analytic framework, this study concentrates on three different aspects on aesthetics of physics. First, in regard to the aesthetic features of physics, this study relies upon general dichotomy of aesthetics to examine the aesthetic features of physics. Aesthetics originates from the Greek philosophy to investigate the reality, and modern philosophy of aesthetics is based on Kant’s theory of aesthetic attitude.

Greek philosophers regarded aesthetics as intrinsic value of objects centring on harmony and order. Until seventeenth century, aesthetics had been viewed as intrinsic nature of an object, which could be aware by reason. With the emphasis on affective dimension of human since the eighteenth century, aesthetic philosophy began to take into account extrinsic way to aesthetic judgment based on affection and personal judgment. In spite of no consensus about the essence of aesthetics, it is usually classified into intrinsic and extrinsic aspects.

Formal expression which belongs to an object or a phenomenon can be counted as intrinsic aesthetics such as line, shape, colour, symmetry, and balance, whereas cognitive or affective judgment can be understood as extrinsic aspect of aesthetics such as sublimity, elegance, awe and wonder. Based on such a division, this study intends to find out aesthetic features of science stated in the selected theses following taxonomy analysis. Second, this study categorises the object of aesthetics into natural phenomena and theories and principles in physics.

The analysis is to investigate whether aesthetics of science is about nature or is limited to scientific theories. Last, this study analyses approaches on aesthetic of science adopted in the literature based on the history and philosophy of aesthetics, e.g., Hutcheson’s theory of taste, Shaftesbury’s disinterestedness, and Kant’s theory of aesthetic attitude.

**METHODOLOGY**

In this study, many of articles dealing with aesthetics of science including physics are selected from the papers published in international journals of various fields: aesthetics, history and philosophy of science, science education, and even in art criticism. This study analyses the articles in a variety of fields because there are only a few of articles explicitly discussing aesthetics in science and science education.

To conceptualise aesthetics of physics in a broad way, this study examines the articles in the field of art and history and philosophy of science. A combination of several keywords, art, aesthetic, beauty, science and physics, are used for the searching engine, Web of science, one of the biggest database for scholarly prominent journals provided by Clarivate Analytics (before, it was called Thomson Reuters).

Among the articles primarily selected from the database, a total of 88 articles are selected to be analysed, which are indexed in SCI (Science Citation Index), SSCI (Social Science Citation Index), or A&HCI (Art & Humanities Citation Index) since they are explicitly dealing with aesthetics of science or physics. As shown in Table 2, aesthetics of science is tackled in various fields: history and philosophy of science, interdisciplinary studies, science education, science (usually biology), art & design studies, philosophy, education, psychology, and others.
RESULTS AND DISCUSSION

According to the results, the literature presents 26 kinds of formal expression (intrinsic) and 13 kinds of extrinsic representation of aesthetics in science. Twenty-six kinds of formal expressions found in the previous studies are reconceptualised to 11 kinds of intrinsic properties of aesthetics: simplicity, symmetry, harmony, complexity, correspondence, unity, invariance, coherence, visualisation, abstraction and mathematisation. In extrinsic aspect of aesthetics, eighteen kinds of representation are recategorised into 11 kinds of extrinsic properties of aesthetics.

It is interesting to note that intrinsic aspect of aesthetics in science is more referred than those of extrinsic aspect related to affection about physics. Among the intrinsic aspect of aesthetics, most frequent properties are harmony, unity, symmetry, unity, simplicity and coherence. They are connected to the main features of aesthetics, harmony and proportion, which was considered as beauty science the Greco-Roman period. On the one hand, elegance and sublimity is proposed more than others while considering the beauty of science as affection.

Aesthetic properties in physics

Simplicity is often discussed when talking about physics theories. In many cases, physicists tend to believe that the simplest solution is usually correct since it is economical to investigate the factors and fruitful to predict the outcomes. Einstein confessed that he would not be interested in the laws of nature if they turned out not to simple.

In the practice, students seek the simple form to satisfy the given data during scientific inquiries. What makes us perplex is that simplicity is to some extent subjective in spite of its intrinsic nature of physics. Different forms of simplicity cannot be compared with each other. In this case, aesthetic judgment on simplicity is subjective. Even, it should be more cautious while applying simplicity to explanation of modern physics.

Symmetry is a traditional aesthetic property of physics. Weyl (2016) and Zee (2017) addressed a sense of symmetry for the beauty of modern physics. Symmetry helps to find the patterns behind the nature. Even though some appear unrelated, symmetry principle may reveal the identical in the different and finally show the link between physical entities.

However, symmetry is somewhat subjective as well. Weyl (2016) explains several concepts of symmetry: bilateral, rotational, translational, ornamental, and mathematical ones. Among them, translational or ornamental symmetry is connected with personal preference. Even, theoretical symmetry is broken in the experiments. This indicates that the symmetry of physics may fail to explain the experiment and observation.

Harmony in physics is considered as mathematical beauty. It is associated with regularities of numbers and geometric elegance. The concept of harmony originates from Greek aesthetics, harmonia. Order, coherence and unity have the effect of integrating formal features into structures that give the impression of constituting unified wholes, which have great aesthetic appeal.

However, scientists also rely on the intuition or gut feeling in the scientific enterprise. Planck struggled to solve the radiation of heat in the black cavity which was not compatible with Wien’s experimental law. Without empirical evidence, he boldly supposed the discrete state of energy with mathematical extrapolation. The bold assumption without any empirical evidence led them to construct the new model in physics. It is unclear whether harmony in physics is a sensibility to recognize the specific forms or a sense of aesthetics in a human mind or body.
Ontological issue about aesthetics: physics or nature

What makes us confused is the target of aesthetics. Even though aesthetics is mainly classified into intrinsic and extrinsic aspects, both aspects are not exclusive and sometimes points to nature or theory. Sometimes, imperfect sensory organs of a human cause a mistake to understand aesthetics of physics. In this case, we may ask if it is true that nature is aesthetic.

According to Giere, science produces data from observation and experimentation of the real world, and constructs a model to explain or predict the data through reasoning and calculation. Science only talks about the agreement or disagreement between model and data, not between model and the real world. In the eighteenth century, natural philosophers investigated nature not in the laboratory but in the field and tried to re-present natural phenomena, so-called mimetic experiment. From Popperian view, art of nature corresponds to art of science theories.

Accepted aesthetic judgements and preferences are reflected and can be accounted for by the normative principles incorporated in our model. On the contrary, contemporary physics does not support such a naïve realist position about the relation. Major interpretations in quantum mechanics take a negative attitude toward the physical property which are not observable, and due to the interaction between measurement behaviour and physical reality, it is essentially impossible to figure out the appearance of the physical reality.

From the epistemological viewpoint, it is controversial whether aesthetics of physics is identified in a cognitive or empirical way. If aesthetics of physics is intrinsic, the perception should be sensory or intuitive without any reason. However, beauty of science is limited without appropriate understanding of physics. Otherwise, if aesthetics of physics is extrinsic, dependent on human affection, it should be subjective and there should not be anything common in theories of physics.

Many physicists commonly stress the simplicity, symmetry, and unity for physics and even claims the empirical adequacy of aesthetics to justify the truth of theories. In this sense, McAllister argues for rationalist image of science that aesthetics of science can be understood by science knowledge. However, individuals with different aesthetic beliefs may come to reach the different conclusions and pragmatic virtue of aesthetics is not a priori but a posteriori. In other words, aesthetic property of theory does not tell us about the truth about the theory, but only means that a valid theory is accepted as aesthetic consequently. Nevertheless, it is undeniable that there are a number of cases that creative physicists held specified aesthetic views on science and contributed to the formulation of new theories and laws.

Various approaches to the aesthetics of physics

Aesthetics in general is identified with intrinsic and extrinsic aspects. In this vein, aesthetics of physics is an intrinsic property perceived by sensory organs, or a subjective affection by experience or observation. Engler mentioned about the structure of science as aesthetic property of physics. The existence of aesthetics can be divided into naïve realism and transcendental realism afar from the real world. The former postulates the correspondence between theory and nature and aesthetics is behind the natural world, like a veiled woman.

This is similar to worldview of Aristotle and beauty of theory is beauty of nature. Many scientists such as Hooke, Maxwell and Priestley believed that science is a common language to reveal the divine plan. Even Heisenberg said, “I was lucky enough to look over the good Lord's shoulder while He was at work”.
On the other hand, aesthetics is regarded as the sensitive perception evoked from observation or experience. In this sense, beauty is related to some perceiving power. The notion of aesthetics is originally meant as to perceive. Aesthetic judgment is inborn and the criterion of such judgment is personal pleasure. If the power is irrelevant to the object, the talent will enjoy pleasure whatever they see. However, this is not right. Neither does everybody feel pleased with quantum mechanics, nor any theory evoke aesthetic feeling of physics. What if there are some objects which can evoke aesthetic perception, aesthetic appreciation will occur in someone’s mind who have the perceiving power.

The aesthetic attitude is related to the disinterestedness, no pursuit of personal interest. In other words, the person who holds the aesthetic attitude does not perceive objects with some kind of personal interest. For example, we just take a look at the painting in the gallery and feel pleasure in spite of no prior knowledge at all. In this manner, physics can be perceived as beauty without goal-oriented action.

In the literature, many scholars take into account the character of disinterestedness. The aesthetic attitude in physics have two different criteria, empirical adequacy of theories and disinterested fashion with the purely perceptual qualities of the theory. To perform the aesthetic fashion well, one should get rid of any prejudice or a sense of interest in the object.

Even, symmetry plays a significant role in scientific discoveries, and aesthetic evaluation is important in doing scientific inquiries. Aesthetic claims made by scientists can be motivated not only by different accounts of the nature of science, but also by certain specific conceptions of the aesthetic, in particular by the idea that aesthetic appreciation is disinterested.

However, the aesthetic attitude has some problems in the context of physics teaching. According to the theory, attitude is deeply embodied in the mind and reluctant to change. The only thing we can do in the classroom is to teach empirical worth of aesthetic evaluations. Another issue is subjective nature of aesthetics. There is a prejudice that aesthetic judgments are subjective whereas scientific judgments are objective. The notion of intersubjectivity may provide shared ideas about aesthetic evaluations in physics.

Intersubjectivity refers to the common sense or shared meaning constructed by two or more people, which is neither fully individual nor fully universal. Similar terms in the philosophy of aesthetics is synesthesia, which means “the simultaneous, harmonious experience of diverse sensory impressions from complex works of art resulting in a fusion of apparent opposites or unification of differences”. Or, synosia can be an alternative to enhance the aesthetic evaluation.

The word denotes understanding that integrates feeling that one knows with feeling what one knows. In this sense, aesthetic evaluation encompasses both cognitive and affective elements, and can be regarded as empathetic intuition.

CONCLUSIONS AND SIGNIFICANCE OF THE STUDY

Understanding of aesthetics in art is helpful to understand of aesthetics in physics. Since between physics and art share some outcomes as noticing Deeply, embodying, questioning, identifying patterns, making connections, exhibiting empathy, creating meaning, taking action, reflecting and assessing. In this light, the artistic activities may contribute to enhance the beauty of physics.

Even, reframing of data into some simple formula, so-called didactical transposition, is the reframing of knowledge and the related social practices of reference. The representation
of the world and transformation of an image would be helpful to combine visual art and 
natural science in education.

In physics education, teaching aesthetics of physics should be encouraged in order to 
hance students’ views on the nature of science and appropriate image of science. Scientific 
quiry is a kind of aesthetic experience which can evoke various emotions about physics. 
stonishing is that the effort to enhance the internal structure of theories often lead to their 
gressive development and augmentation. The discovery of unexpected outcome can be 
seen as the unreasonable effectiveness, wonder or marvellous emotion of aesthetic 
preciation. The goal of educating physics is to provide students with aesthetic experience 
for the better ability to solve scientific problems and to understand the nature of and the 
ents of physics.

Aesthetic preference is to some extent to creativity in physics. While all creativity 
olves some oscillation between creative and ordinary subselves, the frequency of the 
ossilation should correspond roughly to the amount of constraint involved in the creative 
edium.

Creativity requires continual adaptation of the creative/critical oscillation frequency, 
ich can be most effectively achieved, in the long run, by I-You interactions between 
reative and ordinary (critical) subselves. Which subselves will lead to more intense large- 
cale emergent patterns? The ones that are permitted a large but not too-large amount of 
reative disruption (memory reorganization and hierarchical-system crossover).

Creative subselves tend to fall into this category; everyday subselves tend not to. Even, 
aesthetic factors may influence the formulation and pursuit of theories.

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EXPLORATION OF UBIQUITOUS LEARNING ENVIRONMENT SUPPORTED STEM TEACHING MODE

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ABSTRACT

STEM education has become a popular topic with the high-speed science development and knowledge generation. The main goal of STEM is to promote the cultivation of interdisciplinary problem solving capacity and innovation spirits, which is of significance in reforming the teaching mode from simply knowledge transfer to collaborative knowledge building. Current researches about STEM practices mainly focus on the integration of different disciplines, while failing to provide abundant high-quality resources and timely interactive services for solving problems in learning. Ubiquitous learning environment is an intelligent learning space which can provide learners with adaptive resources and services. Therefore, it could provide support for conducting STEM education. In this study, a new STEM teaching mode supported by the ubiquitous learning environment was proposed based on the existing STEM teaching modes and researchers provide learners with innovative supporting technologies to realise the learning process under the proposed mode. To verify the effectiveness of the mode, this paper designed a teaching case about "decimals" and expect to give an enlightening for further researches.

Keywords: STEM, ubiquitous learning environment, teaching mode

1. INTRODUCTION

STEM (science, technology, engineering, and mathematics) education emphasises the interdisciplinary integration. It is not a simple superposition of science, technology, engineering, and mathematics education. Instead, it is necessary to combine the content of four disciplines into an organic whole in order to better cultivate students’ innovative spirit and practical ability (Morrison, 2005).

The basic goal of STEM education is to develop students’ STEM literacy, which contains scientific literacy, technical literacy, engineering literacy, and math literacy. Therefore, STEM education is a systematic education tool that helps learners learn interdisciplinary knowledge and understand the real world. It is also an effective way to cultivate students' problem solving ability, collaboration ability, and practical innovation ability.

The information literacy of students is very important for the STEM education. In the process of completing the project, students need to have the awareness of applying information technology and be able to use scientific and rational techniques to solve practical problems.
STEM education emphasises scientific inquiry and student collaboration, while current STEM education depends only on the materials teacher provided and could not give the above mentioned services. Under this circumstance the effectiveness is not good.

With the continuous development of mobile internet-based and socialised learning, human’s learning style gradually moves from e-Learning to Ubiquitous Learning (U-Learning). U-Learning provides a learning environment in which the students can learn anytime, anywhere. In the U-Learning environment, with the help of context-aware (sensor) technology and mobile communication technology, learners can get personal supports accordingly (Hwang, Wu, & Chen, 2007).

From this kind of view, U-Learning environment has potential in supporting STEM education. Therefore, the core of this paper looks at how to promote the effect of STEM education with the support of the U-Learning environment.

2. RELEVANT RESEARCH

2.1 The teaching modes of STEM

Many scholars have carried out a lot of research about STEM education during which many kinds of teaching modes were proposed.

2.1.1 “5-E” teaching mode

“5-E” teaching mode is a mode based on constructivist learning theory first proposed by Bybee et al. (2006). The mode contains 5 learning stages: engagement, exploration, explanation, elaboration and evaluation.

Since 2004, the International Technical and Engineering Educators Association (ITEEA) has adopted this teaching mode in the teaching centre of STEM. The main point of the “5-E” teaching mode is that students can build their own understanding of scientific concepts through self-exploration.

Using the “5-E” teaching mode to conduct inquiry teaching helps students develop their analysis and explanation abilities in life. Then, Burke combined the characteristics of STEM and proposed the “6-E” (Engage, Explore, Explain, Engineer, Enrich and Evaluate) learning mode based on the “5-E” teaching mode (Burke, 2014).

2.1.2 PIRPOSAL mode

In 2016, Wells put forward an integrated STEM teaching mode—the PIRPOSAL mode (Wells, 2016), shown in Figure 1. Driven by the need to know, questioning is the central factor of this mode, determining which phase students will engage in throughout the whole process.

The mode emphasises convergent and divergent thinking, including eight learning phases: problem identification, ideation, research, potential solutions, optimisation, solution evaluation, alterations and learned outputs.

There are three main learning activities for each learning phase. This mode is not only a conceptual framework of STEM education, but also a teaching framework that is really used in the classroom.
2.1.3 Streamlined STEM Education Process

Edward Locke constructed a streamlined mode for STEM education from the perspective of macro and lifelong learning, and briefly presents the STEM contents that each student should learn at different learning stages (Locke, 2009), shown in Figure 2.

From what have been introduced above, it can be found that the existing teaching modes provide only operating procedures or links, and do not involve the design and research of related tools and resources, teaching evaluation, and a necessary teaching auxiliary condition during the teaching process.

It means that the teaching mode itself is not complete, and can't provide specific and powerful guidance for the development of STEM teaching. These modes are mostly carried out in the traditional environment, in which the learning resources are insufficient, and students couldn't collaborate with others conveniently. Meanwhile, when students encounter learning problems, they couldn't get timely help from others.
2.2 U-Learning Environment provides Support for STEM Education

U-Learning environment is a learning system that the students can learn anytime, anywhere. It consists of ubiquitous networks, evolving learning resources, cognitive network models, learning community, and ubiquitous computing terminals with contextual awareness (Yu & Cheng, 2009) (Fig. 3).

Interactive teaching platform can well support the implementation of STEM education (Xiang, Liang & Wu, 2011). In STEM education, the U-Learning environment in this study can be seen as an external support to the development of STEM education. It gathers a large amount of knowledge resources, and provides learners with more high-quality, diverse and personalised learning support. Learners can get personalised services anytime and anywhere.

Moreover, students can use the ubiquitous learning community to conduct more convenient collaborative learning with other learners. From this perspective, U-learning system provides an opportunity for the conduct of teaching and learning process in STEM education and it is of great significance to STEM.

3. UTILISING STEM TEACHING MODE DESIGN IN UBQUITOUS LEARNING ENVIRONMENT

STEM education is a teaching practice which is built on research results of constructivism and cognitive science (Sanders, 2008). It focuses on the situation of learning, emphasising that learners participate in activities, projects and problem-solving based learning so that learners can acquire and apply their knowledge in the process of designing and collaborating.

This paper refers to the constructivism theory (He, 1997), and combines Dewey's “learning by doing” theory to propose a STEM teaching mode supported by ubiquitous learning environment (Fig. 4) in order to help teachers’ teaching and lesson planning.
3.1 Project/Question design
The design of projects and questions is the core task of this mode. A well-structured project design can improve the learner's learning efficiency, promote the learning effect, and enable learners to achieve a sense of accomplishment in the learning process. The project design of STEM emphasises integrating knowledge into real problem situations and improving learners' ability to solve practical problems. The design of questions based on an in-depth analysis of the knowledge and the relationship between knowledge, to ensure that the questions can realise the teaching objectives.

3.2 Learning activity design
According to Dewey's "learning by doing" theory, the acquisition of learner's knowledge in STEM education is achieved in the process of completing specific learning tasks and solving practical problems.

The specific design of learning activity in this mode contains three aspects. First, learning group design. STEM education emphasises the collaboration between learners and the completion of projects. The formation of a community needs to be heterogeneously grouped based on learning tasks and learner's characteristics to ensure multiple interactions. Second, division of tasks design. It requires the learning group to carry out effective task assignments based on projects and issues, and ensure that each learner can participate in learning activities. Third, learning rules design. Rules refer to a convention that can coordinate the group to complete learning activities, including rules for participating the activities, tasks, and communications, etc.

3.3 Learning resource and tool design
Learning resources and tool design include curriculum learning resource, information search tools, design and implementation tools, communication and collaboration tools.

Abundant learning resources and tools are essential for STEM education, which is the basis for learners to construct their knowledge. Teachers need to provide learners with appropriate curriculum resources according to their task needs, which can provide guidance and support for learners to solve problems. Besides this, the ubiquitous learning space is very convenient for students to investigate auxiliary materials according to their needs, and it can
perceive learning situations and recommend adaptive learning resources to learners’, which will be very useful for students to get high quality resources.

### 3.4 Learning process design

STEM education emphasises the construction of knowledge, and “situation”, “collaborative learning” and “inquiry learning” are very useful during this process. In ubiquitous learning environment, teachers can create various learning situations in which students can conduct inquiry learning and collaborate with others conveniently. In order to enable learners to achieve learning objectives in specific situations, various learning processes and environments need to be designed.

### 3.5 Learning evaluation design

Learning evaluation is an examine of whether students reached the teaching objectives, which can be used for guiding and improving the teaching. As an interdisciplinary integration of teaching methods, the evaluation of STEM requires a combination of formative and summative evaluations. For the formative evaluation, teacher need to design the evaluation scale and observation scale, which is usually used in the formative evaluation. And for the other, teachers can use the criteria set in advance to adopt intra-group evaluation and inter-group peer review. The STEM teaching evaluation should change the previous single evaluation model, using a variety of methods, from multiple dimensions, perspectives, and entities to evaluate the learner's learning status and task completion.

### 3.6 Human Social network

Social network is like a community combined with learners and their helpers in the ubiquitous learning environment. Learners can exchange knowledge and experience in this community, ask questions, solve problems and share various learning resources together, and during this time, forming interpersonal relationships that interact and promote each other. The social network can provide great support for STEM education, and learners can communicate and collaborate with other people anywhere and anytime.

### 3.7 Resource Network and Tools Library

STEM education depends on the organic integration of specific learning resources and learning tools, and the rich resources and tools library in the ubiquitous learning space can provide good support for learners’ question exploration, project implementation, and model construction. Rich learning resources are an essential condition for constructing cognition. In addition, it is necessary to plan various cognitive tools during the completion of learning tasks to help learners better express problems, represent their own ideas (such as concept maps), communicate with others, and so on, which can promote the cognitive process of students.

### 4. TEACHING CASE DESIGN OF DECIMALS

Decimals are actually another representation of the fraction. Although students have already had a preliminary understanding of the fraction and also learned the rate of carry between different length characters, they still have difficulty in understanding the meaning of decimals and lack capacity to connect specific knowledge and life. The most effective way to solve this problem is to allow students to apply knowledge in project tasks and experience new knowledge in operating practices. In this paper, we choose this content as an example to design a case based on the mode proposed in this paper. The following inquiry-based lessons come from the third-grade children. This case integrates three disciplines: Chinese, Mathematics, and Information Technology.
4.1 Question Design
Q1: Is decimals important to our lives? Why do we use it?
Q2: Do you know where to use decimals in your life?
Q3: There are so many decimals in life. What happens if there is no decimals?

4.2 Learning Activity Design

4.2.1 Learner grouping
The learners are grouped according to their learning style and knowledge level, with 4-5 students in each group. Every group should determine its production direction.

4.2.2 Learning tasks and requirements (see Fig. 5)
Task 1: According to the list of your designs, choose a bazaar commodity with a price of less than RMB 20 yuan. Then take a picture of the product with Pad, and upload the photo to the learning folder of your project.

Task 2: Read out the name and price of the commodity, and record the audio (or video) before uploading it to the project folder.

Task 3: First, classify the collected goods by category. Then, fill in the group summary list with the order of commodity prices. Finally, calculate the number of goods, and share the group file to the whole class.

Task 4: Around the "Bazaar" project, every group need to design and implement an activity plan.

![Learning Task List](image)

Figure 5. Learning tasks and requirements design screenshot

4.3 Learning Process Design

4.3.1 Self-regulated learning process -- Watching the micro-lecture (see Fig. 6)
In this stage, each student need to study the micro-lecture of "The first view of decimals" before class, and complete the pre-class test according to the studying sheet. If anyone has questions, they can seek help on the platform.

Resources and tools: During this stage, teachers are not the only providers of learning resources. The U-Learning environment can also recommend relative learning resources and experts to learners by extracting and analysing the learners knowledge levels.
4.3.2 Practical learning process -- Collect commodities for sale

During this stage, everyone needs to complete task 1 and task 2 by themselves. With the online learning platform, they will know the prices of various products.

Resources and tools: photoshoot tool and online storage tool provided by ubiquitous learning platform.

4.3.3 Collaborative learning process -- Commodity classification activity

Each group should modify their list using decimals to record the price as required, and then count the list of commodities in their group, share photos within the class.

Category 1: Classify according to the number of decimal places.
Category 2: Classify according to the type of commodity.
Category 3: Classify according to the price of the commodity.

During this stage, each group need to complete task 3.

Resources and tools: Presentation tools provided by the Ubiquitous learning platform. Learners can share and communicate with other members within the group through the U-Learning platform, which makes the communication more convenient.

4) Exploratory learning process -- Project design

Each group completes the team plan based on the template provided by the teacher and then make presentations during which all learners could provide suggestions using annotation tools for improvement.

Resources and tools: The digital template and annotation tools provided by the Ubiquitous learning platform.

4.4 Learning Evaluation Design

4.4.1 Evaluation targets: groups and individuals.

The items of the evaluation for the group includes several dimensions: project design, production, teamwork, and sharing of presentations by the learning group; the total score of the group evaluation is 100 points, in which "project design" accounts for 30%, and "work production" accounts for 40%, "teamwork" accounts for 20%, "sharing of presentations" accounts for 10%.
In addition, the individual evaluation of students is divided into two dimensions: individual's performance in the group and their contribution to the group, which accounts for 40%; performance of the learner on the learning platform, which is analysed and calculated by online data (e.g. the data of online discussion, duration of study, submissions, etc.), accounting for 60%. Each student's score is 100 points.

![Learning Evaluation](image)

**Figure 7. Learning evaluation design screenshot**

2) **Evaluation subject: teacher and student.**

According to the "group evaluation scale," each group needs to evaluate the performance of its own group and other small groups. Teachers need to evaluate the performance of all groups. In addition, each student also needs to conduct self-evaluation and co-evaluation.

Resources and tools: evaluation tools and rules provided by the Ubiquitous learning platform (see Fig. 7).

5. CONCLUSION

STEM education, as an interdisciplinary and integrated education form, has received extensive attention in the field of education, but it has not yet formed a relatively comprehensive and generalised STEM education mode. And with the continuous development of mobile communication technology, ubiquitous learning has become a universal learning method.

Ubiquitous learning environment which is based on smart technology can provide effective support for STEM teaching practice.

In this paper, through the combing of the existing STEM teaching mode, based on the constructivist learning theory and the theory of “learning from doing”, we attempt to propose a STEM instructional design under the ubiquitous learning environment. This mode contains several aspects such as “learning activity design, learning resources and tool design, learning process design, learning evaluation design, etc.”. Based on this mode, this study uses the "decimals" as an example to design an STEM course, expected to provide reference for future STEM education practice.
REFERENCES


UNDERSTANDING STEM TEACHERS’ TEACHING: FRAMING GIRL CHILD HOME EXPERIENCES AS CURRICULAR AND INSTRUCTIONAL CONTENT

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ABSTRACT

Education is a fundamental human right and is key to individual, social and national development. It offers the opportunity to realise the attainment of human rights and is an important vehicle for addressing inequality and marginalisation. The performance of the girl child in STEM subjects is low compared to the boy child at primary school level in Kenya. This study investigated the extent to which primary school STEM teachers explain curriculum concepts using Girl child home STEM experiences and knowledge. It was a cross-sectional descriptive survey of 18 randomly selected established public primary schools teachers in the Sabatia division, Vihiga County western Kenya. A semi-structured questionnaire was the main data collection tool.

The findings were summarised using descriptive statistics (Frequencies and percentages). All the analysis was done using statistical package for social sciences (SPSS V.20). Participating teachers ranged from 20 to 61 years of age ($M = 39.55$, $SD = 11.79$) and 23 (46.9%) were aged between 31-40 years. More than half 26 (53.1%) were male and 30 (61.2%) had certificate as the highest level of education attained. All 49 (100%) were trained teachers and 26 (53.1%) had a teaching experience of 10 years and above. Majority, 38 (77.6%) and 34 (69.4%) were teaching maths and science respectively. 43 (87.8%) reported availability of topics that could be linked to the girl child social activities, household chores, pass time or play pattern.

The survey showed that 32 (65%) of the teachers were aware of the girl child background in explaining STEM related concepts. Higher proportion 39 (79.6%) reported to link girl children house/home social activities with the science concepts taught in the classroom. However, a higher percentage of the teachers 30 (61.2%) and 29 (59.2%) reported poor learning attitude and lack of teaching materials respectively as problems encountered when teaching STEM topics in standard five. In addition, higher proportion were males and they do not refer to this home related chores due to social cultural factors which do not allow free interaction between the teenage girl and the male teachers. There is a need for STEM teachers to utilise home knowledge and experience of the parents (mothers) to help the girl child in understanding scientific concepts. Policies formulation should address cultural issue in a way to help
eliminate gender disparities in academic performance and create incentives to encourage more women to advance in STEM related subjects.

**Key words:** curriculum, incentives, constructivism, policies

**BACKGROUND**

Education is a fundamental human right and is key to individual, social and national development. It offers the opportunity to realise the attainment of human rights and is an important vehicle for addressing inequality and marginalisation.

UNESCO, UNICEF, and other non-governmental organizations have been conducting research aimed at improving female access to education (Kairu, Kola, & Momanyi, 2000). Buchmann (2000) reports that, three perspectives generally inform determinants of educational inequality: economic, resource constraints, and cultural perspectives. Each of these perspectives has been used to explain educational decision making in developing countries, and each predicts participation in formal schooling.

In the case of Kenya, cultural norms and gender stereotypes do hinder girls' participation in school, where typically mathematics and science are seen as ‘boys subjects’ while home science is a ‘girls’ subject’. Some reports indicate that although Kenya has high levels of primary school enrollment, data show that as girls enter secondary school, their teenage years, their enrollment begins to fall compared to that of boys (Lloyd, Mensch, & Clark, 2000).

Since independence Kenya has been pursuing policies towards the realisation of equal access to education of both boys and girls as demonstrated by being a signatory to the International Conventions and Agreements on human rights and gender equality.

The Government has put in place several interventions such as the introduction of Low Cost Boarding Schools and Mobile Schools in Arid and Semi-Arid Lands (ASALs). Free Primary Education (FPE) in 2003 and Free Day Secondary Education (FDSE) in 2008, a circular re-entry for girls who drop out of school as a result of pregnancy, affirmative action in the allocation of bursaries, admission of girls into universities, and appointment of qualified female education managers at schools and administrative levels as additional efforts to address gender disparities. All these interventions have led to greater equality in the representation of women and increased opportunities for boys and girls in schools and colleges. However, despite these interventions, the Government is still faced with challenges of addressing aspects of gender equality issues in the Education Sector (Chebari, 2010).

The gender gap, in favour of males, widens as one goes higher up the education ladder.

In addition, it is evident that gender disparities are particularly wide in access to and achievement in Science, Technology, Engineering and Mathematics (STEM) subjects, especially in higher education. Some of the key factors contributing to gender inequality in the sector include socio-cultural and religious beliefs, attitudes and practices, poverty, child labour, poor learning environment, lack of role models, HIV and AIDS, curriculum, pedagogy and learners’ attitudes among others (Levin & Nolan, 2013; Maloney et al., 2015).

In 2013 the enrolment of boys and girls shows an increase by 2.6 per cent and 0.7 per cent respectively, a slow growth for the girls despite free primary education. The enrolment in secondary schools by class and sex from 2009 to 2013 indicates that the total enrolment of boys rose by 10.7 per cent while that of girls increased by 9.0 per cent (Government of Kenya [GOK]/UNICEF, 2014). The retention rate for girls was 88.0 per cent compared to
boys at 92.0 per cent. At university level, while the male student enrolment increased by 42.6 per cent, female student enrolment rose by 25.0 per cent in 2013/14, a clear indication of disparity in favour of males. Enrolment of women at university is mainly in the fields of social sciences, humanities, services and health related programmes. Studies, such as one by Capobianco, Diefes-dux, Mena, and Weller (2011), also indicate that some STEM subjects are viewed as ‘male’. For instance, when young pupils were asked to draw pictures of engineers, the majority drew a man.

The Kenya Institute of Curriculum Development has made strides in addressing gender issues in the development of curriculum and curriculum support materials. However, more effort is required in the education sector to address pedagogy, teaching/learning processes and the entire student-teacher interaction in school that reflect gender biases, stereotypes and insensitivity. These contribute to the perpetuation of gender disparities and inequalities in the STEM related fields (Glennerster, Kremer, Mbiti, I., & Takavarasha, 2011; GOK, 2007).

During Primary School Science Syllabus coverage, some teachers provide diagrams and physical materials for the students to identify. From such demonstrations, students relate the learning to what they already know or what they encounter at home. This is related to Contextual learning theory (Hull, 1993) which portrays learning as occurring only when students process new information or knowledge in ways that make it meaningful in their frame of reference.

According to Hull (1993), this approach assumes that the mind naturally seeks meaning in a context by searching for relationships that make sense. Thus, students learn better if they can relate the concepts to what they encounter in their day-to-day life. In Kenya, culture normally define roles and duties according to gender. The girl child has defined roles which they have to adhere to from very early stage in life. The chores are related to different communities but most of them cut across the Kenyan rural tribes. The girls encounter many scientific phenomena in cooking, fetching firewood, cleaning utensils, fetching water for different domestic needs etc. They are decision makers when it comes to day to day running of the family (deVries & Zan, 2003). Any reference to types of vegetables or fruits would not only ring a bell but would raise interest in learning the related scientific concept. We believe that this would be a better approach to teaching and learning among girls. STEM teachers can make reference to items or processes that are familiar to Kenyan girl child (Klassen, 2006; Nashon & Anderson, 2013).

Accordingly, contextual learning is organised in ways that allow students opportunities to engage in real world problem solving activities (Karweit, 1993). Learning in meaningful contexts has been determined to be effective (Carraher, Carraher & Schleimer, 1985). As noted by Resnick (1987), decontextualising Science learning has no meaning for the students since it is seen to lack relevance outside of the school.

**GENERAL OBJECTIVE**

To investigate the extent to which primary school STEM teachers explain curriculum concepts using girl child home STEM experiences and knowledge.

**METHODOLOGY**

The study was conducted in Sabatia Division, Vihiga County, Western Kenya. It employed a cross-sectional descriptive design that adopted both qualitative and quantitative methods. The study targeted 54 randomly selected teachers in 18 randomly selected
established public primary schools. The sample for the study was selected using a two-stage probability sampling procedure. The instrument used for this study was a questionnaire. It contained questions on demographic characteristics, teachers’ identification of science and mathematics as key curriculum concepts, and their knowledge in planning their respective STEM based disciplinary instructions.

To ensure validity of the instruments, the researcher sought expert evaluation from the Faculty of Education, Kibabii University. Split Half method was used to assess reliability of instruments where a Pearson product moment correlation value of 0.85 was obtained, thus making the instruments to be considered reliable.

Prior to the survey, authority to conduct the survey was sought from the National Council of Science, Technology and Innovation (NACOSTI). In addition, permission was obtained from the county offices of education at both the County, division and school levels. Written informed was obtained from the participating teachers and participation was on voluntary basis. No form of identification was used in the study tools and the completed copies were kept under lock and key. Computerised data was password protected.

Data entry and analysis were done using Statistical Package for Social Science (SPSS V.20). Descriptive statistics (Mean (SD), frequencies and percentages) were used to summarise the data. Qualitative data was analysed thematically.

**FINDINGS**

The response rate was 49 (90.7%)

**Demographic Characteristics of the respondents**

Participating teachers ranged from 20 to 61 years of age ($M = 39.55$, $SD = 11.79$) and 23 of them (46.9%) were aged between 31-40 years. More than half 26 (53.1%) were male and 30 (61.2%) had certificate as highest level of education attained. All 49 (100%) were trained teachers and 26 (53.1%) had a teaching experience of 10 years and above.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Frequency</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age ( in years)</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤30</td>
<td>5</td>
<td>10.2</td>
</tr>
<tr>
<td>31-40</td>
<td>23</td>
<td>46.9</td>
</tr>
<tr>
<td>41-50</td>
<td>8</td>
<td>16.3</td>
</tr>
<tr>
<td>51-60</td>
<td>11</td>
<td>2.4</td>
</tr>
<tr>
<td>&gt;60</td>
<td>2</td>
<td>4.1</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>26</td>
<td>53.1</td>
</tr>
<tr>
<td>Female</td>
<td>23</td>
<td>46.9</td>
</tr>
<tr>
<td><strong>Education level</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Certificate</td>
<td>30</td>
<td>61.2</td>
</tr>
<tr>
<td>Diploma</td>
<td>12</td>
<td>24.5</td>
</tr>
<tr>
<td>Higher Diploma</td>
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<td>2.0</td>
</tr>
<tr>
<td>University</td>
<td>6</td>
<td>12.2</td>
</tr>
<tr>
<td><strong>Qualification</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trained teacher</td>
<td>49</td>
<td>100.0</td>
</tr>
<tr>
<td>Untrained teacher</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Residence</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Forty-five (91.8%) reported to have other duties within the school or related to their teaching profession, of which a majority 11 (28.2%) reported being the Head of Science as in Figure 1 below.

![Other duties within the school](image)

**Fig 1. Teachers other duties within the school**

More than half the teachers 26 (53.1%) had teaching experience of 10 years and above. Only 8 (16.3%) teachers had teaching experience below 5 years (Figure 2).

![Teaching experience](image)

**Fig 2. Teaching experience**

As in Figure 3, 38 (77.6%) of the teachers were teaching maths, 34 (69.4%) science and 4 (8.2%) home science.
Table 2. Identified key, science, mathematics curriculum concepts that could be linked to household chores carried out by girls

<table>
<thead>
<tr>
<th>Subject</th>
<th>Topic</th>
<th>Related activity, household chores and game</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>Food and nutrition</td>
<td>Cooking, washing hands before eating, sharing meals</td>
</tr>
<tr>
<td></td>
<td>Proper storage of medicine</td>
<td>Keeping medicine out of reach of children</td>
</tr>
<tr>
<td></td>
<td>Separating mixtures</td>
<td>Sorting threads, stones etc.</td>
</tr>
<tr>
<td></td>
<td>Health education</td>
<td>HIV/AIDS</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Fractions</td>
<td>Sharing food,</td>
</tr>
<tr>
<td></td>
<td>Numbers /budgeting</td>
<td>Taking positions in a game so as to win, counting during rope jumping, buying and selling and getting balance</td>
</tr>
<tr>
<td></td>
<td>Operations</td>
<td>Game of arranging and counting items</td>
</tr>
<tr>
<td>P.E</td>
<td>Ball game</td>
<td>Playing the game and singing</td>
</tr>
</tbody>
</table>

Incorporating girl child background experience and knowledge in planning respective STEM based disciplinary instructions

Majority of the teachers 39 (79.6%) reported ever linking girl children house and home/social activities with the science concepts taught in the classroom. The linkages reported included; counting, washing utensils, drawing patterns/diagrams, rope skipping, cooking and childcare (Table 2).

Among those that do not link, the main reason was that there was no time for such reference 10 (100%). The problems encountered when teaching STEM included poor learners attitude 30 (61.2%), lack of teaching materials 29 (59.2%) and the syllabus being wide 25 (51%) among others as in Figure 4.
CONCLUSION, RECOMMENDATION AND IMPLICATIONS

Linkage of girl children house/home social activities with the science concepts taught in the classroom is done. However, poor learning attitude and lack of teaching materials are problems encountered when teaching STEM topics. In addition, a higher proportion of teachers were males and they do not refer to this home related chores due to social cultural factors which do not allow free interaction between the teenage girl and the male teachers.

The study recommends the use of female teachers as role models to help hone girls’ interest in science related subjects and subsequently, science oriented professions. There is need to make a deliberate effort to minimise the widely held but erroneous notion that science and technical disciplines are a preserve of the male gender. A prototype known as ‘job shadowing’ that involves attaching interested girls under technical professionals to expose them to the field for brief periods was cited as an ideal affirmative action to influence their choice of scientific disciplines.

Retention begins with ensuring that no girl who wishes to pursue STEM fails to do so because of lack of resources. Giving more HELB loan to STEM students is a great start. Those who have pursued it further need to know that careers in these fields will be devoid of bias against women and will be flexible to the realities of being a working mother.

REFERENCES


HOW INVERSÉ MERGED WITH GO: REDESIGNING GAMES AS MATHEMATICAL AND CULTURAL PRACTICES

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ABSTRACT

This paper discusses a study that explored a math learning approach of redesigning board games. Considering how game design literacy engages learners in understanding and creating a complex set of meanings, we investigated how game design activities help learners engage in mathematical and cultural practices as part of their learning process in a Western Canadian elementary school. We collected qualitative data, including video recordings of classroom and photos of students’ in-progress and final game designs. In this paper, we chose one student, Jian, who recently immigrated to Canada from China and made a unique contribution to this task. In redesigning the game, Inversé, he and his partners adopted the rules from an ancient but still popular game, Go, while engaging in mathematical thinking of area, multiplication and estimation. Jian’s work demonstrates how the learning activities involved in redesigning games encourage learners to bring in their cultural/personal resources while engaging in mathematical thinking.

Keywords: Mathematical thinking, game design literacy, design-based learning

INTRODUCTION

The study described in this paper explored a math learning approach of redesigning board games. Game design literacy is an important resource for current and future learning of any discipline. It enables learners to understand and create a complex set of meanings (i.e., creating rules) and to anticipate players’ actions and engage in creating and modifying rules (Kim & Bastani, 2017).

We worked with elementary teachers as research partners to design and study how learners redesign games for math learning. We observed that designing games helped learners connect specific disciplinary expertise in mathematics to creating a system (i.e. problem solving, mathematical reasoning, making connections between mathematics and its applications).

Mathematical thinking is an important part of everyday practices, such as assembling, coordinating and communicating resources at a household (Stevens et al., 2006), and is supported by bodily interactions such as gestures and movements in the physical environment (Alibali & Nathan, 2012). Designing games involves modelling a working system and its rules, where players manage resources to progress, engage in movements and actions in the modelled world, through play (Salen & Zimmerman, 2006). As such, game design practices provide ideal activities for developing mathematical thinking.

We also pay close attention to how learners position themselves as learners and bring in their cultural resources and identity through the game design process. Students’ sense of who they are as mathematics learners influences learners’ current and future performance (Heyd-
Metzuyanim, 2015). Based on the research on learner-generated designs (Kim, Tan, & Bielaczyc, 2015), we suggest that learning mathematics through game design will facilitate learners’ ownership and agency in mathematics learning and positively affect students’ mathematics identity. The collaborative design process required learners to determine the use of mathematics knowledge, and to make decisions among varying design ideas.

Our intention was for learners to identify as creators of rules and interactions using mathematics as a tool. In this paper, we specifically investigate how game design activities help learners engage in mathematical and cultural practices as part of their learning process. Our analysis is based on one student’s work in collaboration with two other group members in a Grade 3/4 classroom in a Western Canadian public school.

RESEARCH

Using design-based research (DBR) (Collins, Joseph, & Bielaczyc, 2004), we collaborated with teachers in designing approaches to engage learners in game design practices and conducting reflective inquiry in their classrooms. This paper discusses the second project as the modified iteration. The first project, which we discussed in STEM conference in 2016 (Kim & Bastani, 2016), involved Grade 8 students designing interdisciplinary games from the scratch. The current study was focused on Grade 3/4 mathematics through redesigning an existing game, Inversé.

DBR PHASES OF THE CURRENT PROJECT

Taking the perspective of “partnership” (Coburn & Penuel, 2016), we worked with our teacher partners to create possible designs for learning. During the first phase of this project, the research team explored various design questions informed by the literature and their own teaching practices. In consultation with a board game designer, we played and redesigned board games and tested them out with our undergraduate and graduate students.

The second phase was focused on design workshops with seven teachers of one public inner-city school, which invites many new immigrants with diverse linguistic backgrounds due to its convenient location within the city downtown. In these workshops, teachers played games that we selected, engaged in redesigning those games, and brainstormed how they could engage their students in game design activities. The teachers developed game-design activities for mathematics learning, tailored to their own classes. The third phase, discussed in this paper, was one of the classroom enactments based on the design workshops.

Figure 1. Inversé (Photo: boardgamegeek.com)
Grade 3/4 game design projects

The class was a combined grade 3 and 4 class co-taught by Ms. Gagne and Mr. Ahmadi, with Ms. Gagne’s lead. During January 2018, the teachers started by having students play a variety of games that had some relevance to their math topics. Students and teachers decided *Inverse* as a good game to redesign to deepen their understanding of area, multiplication, and estimation. *Inverse* is a two-persons game in which each player has 5 pieces of wooden blocks of different sizes and colours.

Players place their pieces on a wooden playing board until a player can no longer place a piece. It has three simple rules: (1) same colour pieces cannot touch; (2) same colour pieces cannot be placed in the same orientation; and (3) same height pieces cannot touch, as shown in Figure 1. The following is the flow of the lessons for the game design project:

1. Determined the overall direction as a class to redesign *Inverse* (from 3D woods to 2D papers), and came up with individual design ideas
2. Formed seven groups to integrate ideas into one game per group (January 31)
3. Drafted their games by incorporating math (demonstrating their estimation and multiplication skills for area) and deciding on the game components (e.g., game board, pieces, dice, etc.) and their sizes (February 5)
4. Play-tested with their peers to make rules clearer and to create rulebooks (February 7)
5. Improved upon their rulebooks by using pictures and texts, and creating titles (February 23)
6. Created good game copies by using grid papers, modifying board/piece sizes and cutting pieces (February 29)
7. Finalised game pieces and boards to prepare them to be played by another class and co-created feedback template (March 5)
8. Revised their rules, pieces, and rulebooks based on the feedback (March 15)

Data collection and analysis

The initial game redesign process was already on the way when we started collecting data. As partners, the teachers and the research team had on-going conversations about how to support learners’ work, e.g. by suggesting different design constraints based on the classroom events. We collected ethnographic data through field notes, video-recordings of classroom and photos of students’ in-progress and final game designs. At times, teachers and students collected GoPro videos without our presence.

We had consents for 17 students. For this paper, we chose one male student, Jian, as he was making unique contributions. He had immigrated to Canada from China three months earlier. For this preliminary analysis, we relied heavily on our observation notes as Jian often spoke Chinese with another student from China and his responses to our informal questions were very brief.

Taking the perspective that individual students’ design work will be reflections of their multiple lifeworlds, we observed how Jian’s engagement in this classroom demonstrated his perception of worlds surrounded him. Following Roth’s (1999) use of the term lifeworlds, we identified how the social and material space of this particular classroom encouraged and maintained collective shaping of the world as well as integration of individual lifeworlds (Jian’s cultural-historical experiences).
DESIGNING BLOCKADE AS MATHEMATICAL AND CULTURAL PRACTICES

In redesigning the game, *Inversé*, Jian and his partners adopted the rules from an ancient but still popular game, *Go*, while engaging in mathematical thinking of area, multiplication, and estimation. Here, we describe the world of this particular classroom and its habitus, and interrogate how Jian, who had lived in this classroom only for few months, brought in his cultural/personal resources to the game design while engaging in mathematical thinking.

The social and material world of the classroom and its habitus

Throughout our observations, each class took a typical format of starting as a big group, i.e., students sat around Ms. Gagne on the floor to discuss the overall design tasks and suggestions for the day. As students started working in groups, teachers joined the groups to support the development of their ideas and designs. At the end of the class, students gathered back on the floor surrounding Ms. Gagne, shared ideas and progresses, and discussed the next plans.

On January 31, using their individual design ideas from previous sessions (based on their experience with *Inversé* and the decision to create 2D versions), the students worked in groups to integrate their game design ideas. They were tasked to transform the game rules and change the 3D blocks into 2D rectangles to focus on multiplication and estimation (finding the area of rectangles). Students could choose simple materials (e.g., grid papers, pencils, colour pens, dice, scissors) and decide on how to use rectangles in their games. The groups generally landed on two different methods, i.e., players using pre-determined 2D rectangle pieces or drawing a rectangle with randomly determined sides using two dice. Jian’s group decided to use dice.

Ms. Gagne sat down with Jian’s group. Using the graph paper (and drawing rectangles on it), she started talking about their game rules. She asked questions as, “How do you make a rectangle? How does this rectangle he drew represent the number on dice? What did you roll to get this rectangle?” Jian answered, “you draw twice one side” and the group engaged in some conversations about the relationship between multiplication operations and finding areas.

Ms. Gagne asked again, “I really like the idea of using dice to draw rectangle. Can you think of more rules?” Jian tried to explain ideas about more rules but struggled to find good words in English. Ms. Gagne sustained the conversation by stating her understanding and Jian’s confirming its appropriateness. Communications within the group and beyond were happening in similar ways. At the same time, their drawings of the game ideas facilitated sustaining the flow of communications.

In this particular classroom within this inner-city school, many students were newcomers and language learners or worked with capable peers to eventually become confident English speakers. We observed that English-speaking capability was one of many students’ contributions: the main role of one of Jian’s groupmates was to articulate the game rules in English based on his play experience.

The emergence of different game rules

Adopting new rules, each group’s game evolved overtime. On February 7, Jian group sat with another group and Ms. Gagne, because both groups decided to use one same rule – drawing a rectangle each turn based on two dice rolls. Ms. Gagne was helping them with area calculation. She rolled 3 and 4, and drew a 4×1 rectangle three times to create a 4×3 rectangle.
Another student then rolled 5 and 4 and drew a $5 \times 4$ rectangle in the same way. Ms. Gagne talked about how one could decide where to draw in their games. Jian then said that he had a game and started drawing - blocks (in red) surrounding an opponent’s block (in orange) (see Figure 2).

![Figure 2. Jian explaining the game rule through his drawing](image1.jpg)

After coming up with this rule of surrounding, Jian’s group started playing this game. They used different colours to distinguish different players. Unlike *Inversé*, pieces with same colour and same length could touch in this game. They soon decided that they would also write down the calculated area inside each rectangle (see Figure 3). This seemingly irrelevant (to the game progression) step of writing down the calculation appeared to have multiple functions: (1) as the lines of rectangles unavoidably touch each other, it marked which rectangles belong to which player; (2) some students who had difficulty in multiplications were challenged to find ways to figure out the area (e.g., by counting the squares).

![Figure 3. Jian’s group playtesting their game](image2.jpg)

One of the researchers with an East Asian background suspected that Jian’s idea might come from the game *Go*, but did not know its Chinese name. On March 1, when Jian won their game, the researcher asked him what his strategy was. It seemed that Jian understood it as a question about the game name. He told her it was “*Weiqi*” and then repeated “*Wei*”. He wrote a Chinese character and said it was the game name. He could not find an English word to explain what it meant, so he started to demonstrate by surrounding his classmate. When the researcher said, “*we are surrounding him*”, he was very happy to find a word to describe and repeated “*surround, surround*”. On March 21, a Chinese-speaking graduate student helped with our interview with Jian. We learned that his idea was indeed from the game *Go*, and its Chinese name was pronounced *Weiqi* (圍棋) in the province where Jian was from.
Exploring different rules with dice

We observed the students’ trying different rules for their games and changing their designs to make their games more challenging. One student once commented, “I like that our game is difficult”, to which Ms Gagne jokingly responded, “I wish you can say the same thing about other things we do in class”.

On February 9, Jian’s group had their classmates playtest their game, but with two dice that had numbers 1 to 10 instead of 1 to 6 (see Figure 5, dice in green). Ms. Gagne observed the play and clarified with Jian that a newly drawn rectangle could touch anything on the board. She then asked, “why did you decide to have dice with bigger numbers?” One of Jian’s group member explained that the bigger numbers could cover bigger space and the play would go faster.

The conversation with Ms. Gagne led to their discussion on winning and having a tie. Jian discussed how it might take long to have a winner while others talked about using the calculated areas to determine the winner in the case of a tie (e.g., the person with the bigger sum of the numbers would win). Ms. Gagne helped them understand that with such a rule, the game would not be based on the strategy of players but more on their luck.

The playtests and conversations with Ms. Gagne and classmates helped the group reify their rules and continue to experiment how they could use dice to make the role of luck or strategy stronger in their game. On March 1, we noticed that they have changed their dice back to those with 1 to 6 and determined the appropriate board size for these dice after multiple playtesting.

During our interview, we asked if they would like to change anything about the game. In relation to rolling dice, they suggested that their game, finally named Blockade, could have three versions with different levels of difficulty. The easiest version would use 1 to 6 dice, the next level 1 to 5, and the most difficult one 1 to 3.

DISCUSSION AND CONCLUSIONS

This paper demonstrated how the learning activities involved in redesigning games encouraged learners to bring in their cultural/personal resources while engaging in
mathematical thinking. Game design is an open-ended task. At the same time, using ideas from a pre-existing game (Inversé) could be seen as a constraint that enabled the students to consider other possible resources, especially other games they played.

Activities involved in redesigning games could support them to bring their past experiences into their design activities (in this case their experience with the ancient game, Go), broadening their possibilities for creating new designs. The communications among students could be taken as a roadblock for classroom collaborations when there are students struggling with English.

In this research, the material world of the classroom (reinforced by game design activities) mixed with the sociocultural context of this inner-city school provided more possibilities for sharing and negotiating ideas. The students drew, played, and acted out what they meant while constantly engaging in practices of using math in meaningful manners.

The differences become less a problem for the classroom, but more an important cultural/personal resource. It becomes an asset for their work and strengthens the sense of solidarity (Roth, 1999). Students find a sense of “we”, regardless of how little they can communicate using one of the communication modes in the classroom (i.e., English).

REFERENCES


A HYBRID PROGRAM FOR STEM EDUCATION IN HIGHER EDUCATION: ITS PRACTICE IN FIRST-YEAR EXPERIENCE PROGRAM

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ABSTRACT

In this paper, focusing on the First Year Experience program of STEM students, I examined the effect of a Hybrid Program (configured as Curricular, Co-Curricular, and Extra-Curricular) based on practical cases of accommodation training for four years. It was revealed that a high learning effect can be obtained by improving the self-evaluation of the learner with respect to the attained goal through the inclusion of a “Hybrid Program” in the First Year Experience curriculum. In addition, frameworks from the “Next Generation Science Standards” (NGSS) in STEM education were incorporated into the First Year Experience program, and it is important to expand the curriculum by utilising the framework of the “Hybrid Program” to enhance these abilities. Future tasks include an examination of the curriculum design of the entire STEM education in higher education, in accordance with the background of the learner, including a follow-up survey of students and an expansion of the subjects to be analysed to the entire curriculum.

Keywords: First Year Experience program, Curriculum design, Hybrid Program, Competency of STEM, STEM education of Higher education

INTRODUCTION

Higher education in Japan has entered the era of university entrance, and a variety of reforms are underway, such as reform of the entrance examination system. The needs of students, including their learning needs, are also diversifying. A report by the Central Education Council [CEC] (2014) states that “Zest for living” and “Foster academic ability,” based on the connection from primary and secondary education, should also be cultivated in higher education. This reform covers all fields and also includes STEM students as the following three elements of academic ability from primary education to higher education are required: (1) knowledge, skills, (2) thinking ability, judgment ability, expression, and (3) initiative, collaboration.

The following section focuses on examples from overseas. In the United States, in order to maintain their international industrial competitiveness, STEM human resources are being aggressively developed with the aim of securing and training scientific talent. This is especially the case with regard to the efficient training of STEM human resources, where an expansion of liberal arts education such as the First Year Experience program is proposed as an important policy (PCAST, 2010, 2012).

STEM education has been widely acknowledged in two reports by the President’s Council of Advisors on Science and Technology (PCAST). These PCAST reports focused on primary and secondary education in 2010, and on higher education in 2012, respectively. The substantive objective of the PCAST reports is industrial promotion policy, based on the
recognition that the training of science-based human resources is important for the sustainable development of the United States. Over the next ten years (From this report publish date), the aim is to increase the number of experts and workers (degree holders) in the STEM field by one million people.

Additionally, the National Research Council (NRC) announced the “Next Generation Science Standards” (NGSS) in 2013, which are a revised edition of the “National science education standards”. The NGSS are based on the A Framework for K-12 Science Education (Framework) that was published prior to 2012, and it is necessary to satisfy the elements of the Common Core State Standards (CCSS) and Twenty-First Century Skills (Kumano, 2017).

The NGSS were created to include three aspects in the framework: (1) Practices, (2) Crosscutting Concepts, and (3) Disciplinary Core Ideas (NRC, 2013). Although the NGSS were prepared with correspondence up to K-12 in mind, the connection to occupation, including university education and employment, was also considered and is practically the viewpoint of the educational program up to K-16. The design of the NGSS to train the CCSS and 21st-century skills is used as a core educational concept in STEM education and the promotion of STEM education is closely related to the practice of NGSS.

In Japanese university education, which is required to switch from conventional university education, studies in Extra-Curricular activities are beginning to become the focus of attention, in addition to the ideas suggested in areas such as STEM education. Although university education in Japan has historically tended to focus only on Curriculum-based areas, it is nevertheless necessary to link student activities in the practical community outside the class to learning, or to a practical community that carries out learning activities. Allowing students to participate in such activities will lead to student learning and growth, and the integration of learning experiences gained both inside and outside the class (learning bridging) is beneficial for student learning and growth (Kawai, 2012). It is clear that the importance of positive Extra-Curricular activities and Co-Curricular education is increasing.

There are examples of educational activities being carried out via the Co-Curricular route at two universities in Japan, and based on these definitions, Kuroda (2015) considers Co-Curricular education as “Educational activities and student support activities that are not included in the graduation requirement or which do not grant credits but which teachers and staff engage and support as a whole based on the educational strategy and educational intention of each higher education institution”. In this research, a program incorporating these Co-Curricular, Curricular, and Extra-Curricular activities in a complex manner is defined as a Hybrid Program, with each program of educational activities defining their own Curricular, Co-Curricular, and Extra-Curricular activities that are incorporated into a program.

Therefore, the aim of this paper is to focus on the case of a Hybrid Program in the First Year Experience program for STEM students, analysed from the viewpoint of the framework in NGSS, and examining the effect on students’ learning before and after its introduction.

**OVERVIEW OF THE CASE**

At Ehime University, they reorganised the subjects related to first-year education in 2009, and in 2013 the name “Freshman Seminar” was changed to “Freshman Seminar A”. Following this, the name “Freshman Seminar A” came to be used even in descriptions that pre-dated 2013. Freshman Seminar A is aimed at fostering social skills and study skills. The Faculty of Science aims to develop skills in three areas: social skills, study skills, and career vision. However, in the 2010 description of the syllabus, at least 12 out of the 15 classes contained contents dealing with study skills. They therefore sought to improve the social
skills and career vision elements of the education, undertaking a review of the content of the class and beginning a program to implement the changes from 2011.

This program is positioned as Co-Curricular education, and participation is not compulsory for the students. The provision of programs and a range of exchange opportunities apart from the extended classes is considered to be equivalent to Co-Curricular or Extra-Curricular activities. And if a student is absent from the program, it will be equivalent to lesson hours. Only the task of minutes (for three classes) is supposed to be imposed. Even if they are absent from the program, they would be awarded points corresponding to mini-reports, etc. by submitting an assignment; as such, attention is paid so that attendance on the programs will not directly affect the grades of freshmen in Seminar A.

In addition, they changed the practice that we had divided into two from 2013 to once. It was divided into two at the time of implementation in 2011 depending on the reservation situation of the accommodation facility. They then carried this out twice until 2012, but the number of times was then reduced to lessen the burden on both the faculty and staff. The program was also certified as a tenure-track program and was operated as a program concerning the new faculty of the Faculty of Science.

This case was operated as a complex-type Co-Curricular program, and a senior student from the Faculty of Science participated as a student supporter in charge of providing assistance to participating students and the administration of some of the programs. The trends in participants in the training camps are shown in Table 1. In the results covering the four years, the student participation rate was around 90%. The number of student supporters has doubled compared to the previous years of 2012 and 2014, with around 10 of the supporters having been continuously involved for more than 2 years each year.

### Table 1. Number of Participants

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshmen Seminar A Number of Students (People)</td>
<td>232</td>
<td>228</td>
<td>234</td>
<td>232</td>
</tr>
<tr>
<td>Participating Program (People)</td>
<td>216</td>
<td>217</td>
<td>226</td>
<td>204</td>
</tr>
<tr>
<td>Student supporters (People)</td>
<td>24</td>
<td>41</td>
<td>22</td>
<td>39</td>
</tr>
<tr>
<td>Support Staffs (People)</td>
<td>21</td>
<td>24</td>
<td>20</td>
<td>18</td>
</tr>
</tbody>
</table>

In addition, in this program, they set up their own goals and targets based on the purpose and goals of Freshmen Seminar A, in addition to clarifying the purpose and goal to be implemented for the students. This was widely set up to the extent that it could be dealt with in Co-Curricular education in terms of the ability and nutrition required for the human resources image to be trained, which is difficult to train with just only Curricular alone. In addition, the goal for participating teachers such as the faculty in charge of students in the Faculty of Science is clearly stated, not only the effect with regard to the students but also including elements for faculty development.

Regarding student supporters, the educational effect of this element was evaluated, and this activity has been given some credits from 2014. The implementation programs were improved in each fiscal year, reflecting the results of the previous year’s effectiveness verification and following requests from within and outside the Faculty of Science. Kuroda

The program time was extended as part of the improvement in 2012, and programs equivalent to Co-Curricular education elements were added. It has thus been operated as a Hybrid Program. In fiscal year 2013, due to the reduction in the number of implementations from 2 to 1, it was reported that the programs were changed to respond to the increase in the number of students corresponding, and the program was expanded based on the Tenure Track. It is reported in Kuroda (2015) that the program did not change largely from the practice of 2014, focusing instead on the organizational structure, such as improving the operation system. The programs for each year are shown as follows (Figs. 1 to 4).

**Figure 1. Program of 2011**

<table>
<thead>
<tr>
<th>DAY 1</th>
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</thead>
<tbody>
<tr>
<td>14:15</td>
<td>Orientation</td>
</tr>
<tr>
<td>14:45</td>
<td>Study Skill 1 (Class 1); Curricular</td>
</tr>
<tr>
<td>16:40</td>
<td>Activity and BBQ (Dinner); Extra-Curricular</td>
</tr>
<tr>
<td>20:30</td>
<td>Exchange Party; Extra-Curricular</td>
</tr>
<tr>
<td>7:00</td>
<td>Morning Meeting and Clean up</td>
</tr>
<tr>
<td>7:30</td>
<td>Breakfast</td>
</tr>
<tr>
<td>8:30</td>
<td>Activity; Extra-Curricular</td>
</tr>
<tr>
<td>8:45</td>
<td>Study Skill 2 (Class 2); Curricular</td>
</tr>
<tr>
<td>10:45</td>
<td>Social Skill and career vision (Class 3); Curricular</td>
</tr>
<tr>
<td>12:10</td>
<td>Wrap up Session</td>
</tr>
<tr>
<td>12:30</td>
<td>Lunch</td>
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<tr>
<td>13:30</td>
<td>Break up</td>
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</table>

**Figure 2. Program of 2012**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>10:30</td>
<td>Orientation</td>
</tr>
<tr>
<td>10:45</td>
<td>Study Skill 1 (Class 1); Curricular</td>
</tr>
<tr>
<td>12:30</td>
<td>Lunch</td>
</tr>
<tr>
<td>13:45</td>
<td>Discussion with Support Students; Co-Curricular</td>
</tr>
<tr>
<td>15:00</td>
<td>Interview with faculty; Co-Curricular</td>
</tr>
<tr>
<td>16:15</td>
<td>Activity and BBQ (Dinner); Extra-Curricular</td>
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<tr>
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<tr>
<td>7:30</td>
<td>Breakfast</td>
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<tr>
<td>8:30</td>
<td>Study Skill 2 (Class 2); Curricular</td>
</tr>
<tr>
<td>10:45</td>
<td>Social Skill and career vision (Class 3); Curricular</td>
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<tr>
<td>12:00</td>
<td>Lunch</td>
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<tr>
<td>12:45</td>
<td>Wrap up Session</td>
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**Figure 3. Program of 2013**

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<tr>
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<tr>
<td>10:50</td>
<td>Study Skill 1 (Class 1); Curricular</td>
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<tr>
<td>12:50</td>
<td>Lunch</td>
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<tr>
<td>14:00</td>
<td>Social Skill and career vision (Class 2); Curricular</td>
</tr>
<tr>
<td>15:00</td>
<td>Interview with faculty; Co-Curricular</td>
</tr>
<tr>
<td>17:00</td>
<td>Activity; Extra-Curricular</td>
</tr>
<tr>
<td>17:40</td>
<td>Dinner</td>
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<tr>
<td>20:00</td>
<td>Exchange Party; Extra-Curricular</td>
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<tr>
<td>8:00</td>
<td>Breakfast</td>
</tr>
<tr>
<td>9:00</td>
<td>Study Skill 2 (Class 3); Curricular</td>
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<tr>
<td>11:30</td>
<td>Discussion with Support Students; Co-Curricular</td>
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<td>12:45</td>
<td>Lunch</td>
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<td>13:45</td>
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**Figure 4. Program of 2014**

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<tr>
<td>11:00</td>
<td>Study Skill 1 (Class 1); Curricular</td>
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<tr>
<td>12:30</td>
<td>Lunch</td>
</tr>
<tr>
<td>13:30</td>
<td>Social Skill and career vision (Class 2); Curricular</td>
</tr>
<tr>
<td>15:30</td>
<td>Interview with faculty; Co-Curricular</td>
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<tr>
<td>16:30</td>
<td>Activity; Extra-Curricular</td>
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<tr>
<td>17:30</td>
<td>Dinner</td>
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<td>20:00</td>
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<td>8:00</td>
<td>Breakfast</td>
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<tr>
<td>9:00</td>
<td>Study Skill 2 (Class 3); Curricular</td>
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<td>Discussion with Support Students; Co-Curricular</td>
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<td>Lunch</td>
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<td>Wrap up Session</td>
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<td>15:15</td>
<td>Break up</td>
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</table>
**METHOD**

First, the contents of the program. When paying attention to the program contents, pay attention to the Practices in NGSS. Practice has eight identifies: (1) Asking questions (for science) and defining problems (for engineering), (2) Developing and using models, (3) Planning and carrying out investigations, (4) Analysing and interpreting data, (5) Using mathematics and computational thinking, (6) Constructing explanations (for science) and designing solutions (for engineering), (7) Engaging in argument from evidence, (8) Obtaining, evaluating, and communicating information. Consider how each practice is included in each year’s program.

Next, I will examine the educational effect of the Hybrid Program from the perspective of changes over time regarding the self-evaluation of the target attainment, using the results of the questionnaire survey conducted after the completion of the program for the period 2011–2014 (see Table 2). The question for this goal is an item related to the Curricular element (3 classes), and the degrees of accomplishment for the reaching of each target are “strongly agree” as 4, “I think so” as 3, “I do not think so very much” as 2 and “I do not think so at all” as 1. Responses were obtained by four methods.

**RESULTS AND DISCUSSION**

First, we examine how much the program contains 8 Practices in NGSS. Table 3 summarises the relationship between practiced programs and Practice in NGSS. Although features are seen for each type of program, it became clear that by incorporating all elements as a Hybrid Program, all elements of the eight Practices in NGSS are included.

Some of the questions were changed in 2013; one-factor analysis of variance was conducted for those questions (questions 1 to 6) that had not changed in practice for four years. As a result, there were four questions (equality questions 1, 2, 3, 5) on which equal variance could be assumed (questions 1, 2, 3, 5). Of the four questions that can be considered equally distributed, only question 1 has a main effect at the 0.5% level; \( F(3,840) = 4.571, MSe = 0.361, p < .005 \). In addition, in the multiple comparison (Tukey HSD), a significant difference was found between 2012 and the other years, suggesting that a strong affirmation was made regarding this question compared to other years.

<table>
<thead>
<tr>
<th>Table 2. Number of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
</tr>
<tr>
<td>Freshman Seminar A (People)</td>
</tr>
<tr>
<td>Participating Program (People)</td>
</tr>
<tr>
<td>Number of Respondents (People)</td>
</tr>
<tr>
<td>Response Rate (%)</td>
</tr>
</tbody>
</table>
In a comparison between 2011 and 2012, before and after the introduction of the Hybrid Program, there was a significant difference of 1% level or more in three out of eight questions in the two-year comparison by t-test (Table 5).

Therefore, it is considered that the introduction of a complex-type program yields a positive effect on learning contents.

### Table 3. Programs elements for NGSS practice

<table>
<thead>
<tr>
<th>Program contents</th>
<th>Practice List</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Study Skill 1 ; Curricular</td>
<td>●</td>
</tr>
<tr>
<td>Study Skill 2 ; Curricular</td>
<td>●</td>
</tr>
<tr>
<td>Social Skill and career vision; Curricular</td>
<td>●</td>
</tr>
<tr>
<td>Discussion with Support Students; Co-Curricular</td>
<td>●</td>
</tr>
<tr>
<td>Interview with faculty; Co-Curricular</td>
<td>●</td>
</tr>
<tr>
<td>Activity and BBQ (Dinner); Extra-Curricular</td>
<td>●</td>
</tr>
<tr>
<td>Exchange Party; Extra-Curricular</td>
<td>●</td>
</tr>
<tr>
<td>Activity; Extra-Curricular</td>
<td>●</td>
</tr>
</tbody>
</table>

Table 3. Programs elements for NGSS practice

---

< Practice List >

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

---

### Table 4. Curricular element Goals ANOVA (2011-2014)

<table>
<thead>
<tr>
<th>SUM of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>multiple comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1] I can make appropriate citations</td>
<td>Year</td>
<td>4,945</td>
<td>3</td>
<td>1.648</td>
</tr>
<tr>
<td></td>
<td>Error</td>
<td>302,917</td>
<td>840</td>
<td>0.361</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>307,861</td>
<td>843</td>
<td></td>
</tr>
<tr>
<td>[2] I can explain the difference between taking notes in high school and university</td>
<td>Year</td>
<td>2,047</td>
<td>3</td>
<td>0.682</td>
</tr>
<tr>
<td></td>
<td>Error</td>
<td>357,322</td>
<td>846</td>
<td>0.422</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>359,369</td>
<td>849</td>
<td></td>
</tr>
<tr>
<td>[3] I can explain how to find the point and how to write it</td>
<td>Year</td>
<td>1,463</td>
<td>3</td>
<td>0.488</td>
</tr>
<tr>
<td></td>
<td>Error</td>
<td>353,806</td>
<td>846</td>
<td>0.418</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>355,269</td>
<td>849</td>
<td></td>
</tr>
<tr>
<td>[4] I can take easy-to-understand notes</td>
<td>Year</td>
<td>3,154</td>
<td>3</td>
<td>1.051</td>
</tr>
<tr>
<td></td>
<td>Error</td>
<td>447,738</td>
<td>845</td>
<td>0.530</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>450,893</td>
<td>848</td>
<td></td>
</tr>
</tbody>
</table>

---

"** : p < .05"
Table 5. Curricular element Goals t-test (2011-2012)

<table>
<thead>
<tr>
<th></th>
<th>2011 Mean (SD)</th>
<th>2012 Mean (SD)</th>
<th>t</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.91(0.589)</td>
<td>&lt;3.10(0.537)</td>
<td>-3.29</td>
<td>417</td>
</tr>
<tr>
<td>2</td>
<td>3.19(0.653)</td>
<td>3.24(0.642)</td>
<td>-0.799</td>
<td>421</td>
</tr>
<tr>
<td>3</td>
<td>3.00(0.666)</td>
<td>3.10(0.591)</td>
<td>-1.63</td>
<td>421</td>
</tr>
<tr>
<td>4</td>
<td>3.10(0.672)</td>
<td>3.10(0.652)</td>
<td>0.0510</td>
<td>421</td>
</tr>
<tr>
<td>5</td>
<td>2.86(0.697)</td>
<td>2.89(0.734)</td>
<td>-0.383</td>
<td>421</td>
</tr>
<tr>
<td>6</td>
<td>2.92(0.695)</td>
<td>2.98(0.659)</td>
<td>-0.921</td>
<td>421</td>
</tr>
<tr>
<td>7</td>
<td>2.71(0.823)</td>
<td>&lt;2.97(0.800)</td>
<td>-3.27</td>
<td>421</td>
</tr>
<tr>
<td>8</td>
<td>3.26(0.588)</td>
<td>&lt;3.42(0.608)</td>
<td>-2.77</td>
<td>420</td>
</tr>
</tbody>
</table>

※ *: p < .01  ***: p < .001

CONCLUSION

In this paper, I have focused on Hybrid Program case studies in the First Year Experience program for STEM students, analysed from the viewpoint of framework in NGSS, and examined the effect on students learning. As a result, it became clear that the First Year Experience program contains many of the elements from the NGSS framework, and practical opportunities can be increased by implementing a Hybrid Program. In addition, it became clear that self-evaluation in relation to reaching Curricular goals improves by using a Hybrid Program. Therefore, it has become clear that the level of practical opportunities is expanded with a Hybrid Program, and the opportunities for collaborative learning are increased, so that a positive effect is seen only for Curricular education.

However, there are many problems in this research. First of all, since the students are different in each program according to the program being followed, it is necessary to consider the dependence of the students for each year. Also, since there is a self-evaluation element, it is necessary to examine the relationship with students’ actual literacy ability. Future tasks include an examination of the curriculum design for the whole of the STEM education in higher education, in accordance with the background of the learner, including a follow-up survey of students and an expansion of the subjects to be analysed to the entire curriculum.

ENDNOTE

This paper reconstructs part of the master’s paper by Kuroda (2015), and it revises and adds new ideas and collected data.

ACKNOWLEDGMENTS

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ABSTRACT

This paper introduces an immersive learning environment – Grafemos – that is designed for learning about complex systems that integrates two ways of knowing (epistemologies): Indigenous perspectives on design and complexity, and Western scientific and technological perspectives on computational modeling and complexity. Using Grafemos, learners can learn about complex systems by engaging in the design and creation of a non-computational language for modeling (i.e., representing and explaining) emergent phenomena. Emergent phenomena are complex, non-linear processes (e.g., ecological interdependence) arise from simple, linear interactions between many individual agents (e.g., simple interactions between predators and prey). The modeling experience – in particular, the language design process - draws upon from both Indigenous practices of storytelling in the context of fabric design and Western scholarship on complex systems education. Our paper seeks to advance educational research by contributing to both the fields of K-12 STEM education, and decolonization in STEM education by demonstrating how complex systems education can offer a venue for bringing together Western and Indigenous perspectives on teaching, learning and complexity.

Keywords: Indigenous perspectives, complexity, decolonization, STEM

INTRODUCTION

Although research on complex systems in K-12 education has been typically grounded in Western perspectives, it emphasises the importance of understand emergent phenomena through building individual-environment relationships (Dickes, Sengupta, Farris, & Basu, 2016; Levy & Wilensky, 2008; Wilensky & Resnick, 1999). Emergent phenomena are complex, non-linear processes (e.g., ecological interdependence) arise from simple, linear interactions between many individual agents (e.g., simple interactions between predators and prey). In a deeply synergistic manner, the sense of relationship and reciprocity with the greater-than-human world is foundational to Indigenous cultures and research (Bastien, 2003; Cajete, 1994), and it bears promising similarity to the beliefs of many contemporary Western environmental philosophers, educators, and researchers (Naess, 1990).

We believe that complex systems education can offer a productive meeting point for both Indigenous and Western epistemologies. However, integrating Indigenous traditions and practices necessitates designing new forms of modeling in partnership with Indigenous communities, rather than relying on using common computational modeling and
programming platforms for modeling complex systems designed by Western scholars. As Clark (2004) pointed out that we must labor to reconfigure the colonial frames of minds affecting our consciousness that in our case, has historically limited our vision to Eurocentric technologies and modes of representing complexity. In this paper, we present a theoretical review of synergistic frameworks from both Indigenous and Western perspectives, and illustrate a modeling experience for learning about emergence. This experience involves a language design process draws upon from both Indigenous practices of storytelling in the context of fabric design and Western scholarship on complex systems education.

THEORETICAL BACKGROUND

Knowing as Connected Action: Views from Indigenous Perspectives

In Indigenous perspectives, knowing is viewed as a dynamic experience, that is at once historically shaped, as well as involves establishing connections with our environment and fellow citizens (Cajete, 2004; Kovach, 2017; Montejo, 2010). This stands in contrast viewing knowing as acquisition of discrete skills, which is a view that is commonly cited by Western psychologists (e.g., Anderson, 1982). In Indigenous perspectives, knowing is multi-modal and practiced in cultural forms: ceremonies, languages, traditions, costumes, thoughts, Indigenous philosophies, and others. Key characteristics of Indigenous forms of knowing, as identified by Indigenous scholars, are: holism (implying empirical, experimental, sensory, and metaphysical possibilities), interconnectivity and interdependency, dynamic, arising from the multiplicity of resources including non-human sources, and created through communities, readings, elders, and traditions (Cajete, 2004; Kovach, 2017; Otzoy, 1992).

Across these characteristics, locality plays an important role. The place is more than a location where people live; they are spiritually connected to the place, it represents their point of reference in their lives. In many cultures, this is referred to as “Mother Earth” (Hatcher, Bartlett, Marshall, & Marshall, 2009, p. 147). In these local worlds, space and time perspectives are cyclical (Snively & Corsiglia, 1998). The cycles of observation are made over “several life times…in all seasons” in one place (p.18), gained through observation of natural events, taught and learned as stories that contain rich scientific details, and wrapped in metaphors that are may be culturally familiar even beyond the local community. Indigenous communities pursue different branches of knowledge (i.e., mathematics, problem solving, navigation, medicine, ecology, astronomy, military strategies) and the “subject matter is properly examined and interpreted contextually” (Snively & Corsiglia, 1998, p. 13).

Knowing is thus a shared action that belongs to the community and not to an individual (Kovach, 2017; Ogawa, 1995). Knowing is also dynamic – i.e., curated, adapted and appropriated by community members in the form of narratives and cultural artifacts, over multiple generations (Montejo 2010; Ogawa, 1995). The manifestation of forms of knowing is heterogeneous in nature – in the form of colloquial and specialised languages, as well as technological and cultural innovations, broadly conceived. Examples of such heterogeneous manifestations include linguistic innovations such as specialised terminologies for constellations; locally adapted technological innovations such as boats, traps for hunting that are often specific to individual communities; cultural artifacts such as textiles and narratives that embody generations of cultural history; and local ecological knowledge that is critical for sustainability (Kawagley, Norris-Tull, & Norris-Tull, 1998).

Knowing is thus a multi-generational, collective and complex experience, because it involves observing, inferring, predicting, questioning, experimenting, classifying and adapting – not only at the individual level, but also at the collective level (as a community), as well as over multiple generations (Lowan-Trudeau, 2012; Ogawa, 1995; Snively &
In Indigenous communities, young people are taught by elders to ensure the continuum of their culture, to sustain their ecosystem, and to survive. But this is not a transmissionist model of teaching and learning; on the contrary, it involves learning through narratives and cooperation, as well as the dynamic curation and generation of practices. Indigenous stories, for example, involve narratives about locally adapted practices such as hunting and gathering that can be crucial for survival in certain environments (Kawagley et al., 1998; Ogawa, 1995; Snively & Corsiglia, 1998). Teaching and learning also happen through co-operation, where elders and younger members of the community engage together in modeling the relevant practices in authentic settings (Kawagley et al., 1998). Many of the practices modeled are intimately related to the sustainability of the community and the environment; therefore “successful experimentations … [are] highly valued” as part of these experiences (Snively & Corsiglia, 1998, p.15).

Synergistic Views from Western Perspectives: Constructionism & Complex Systems Education

As Berland, Baker, & Blikstein (2014) pointed out, in the constructionist paradigm, learning involves building and designing creative artifacts that require complex forms of intellectual engagement, alongside high levels of affective involvement (Papert, 1980; Papert & Harel, 1991). Constructionist learning is typically grounded in learners’ use of generative computational technologies in disciplinarily as well as personally meaningful forms. Rich illustrations of constructionist learning also involve creation of public artifacts and working in social spaces such that learners can collaborate to deepen their learning experiences (Harel, 1990; Kafai & Burke, 2013; Sengupta, Krishnan, Wright, & Ghassoul, 2015). A constructionist approach to learning supports “detached kinds of knowing” (Papert & Harel, 1991, p.11) where different worlds, identities, languages and understandings can co-exist and intermingle in a particular space or moment.

We therefore posit that constructionist learning environments can offer learners opportunities to experience complex disciplinary forms of knowing as place-making, i.e., by enabling learners to position themselves as creators within the discipline as well as the local community. To this end, Papert and Harel’s (1991) call to action was to design learning environments that can “keep [the] intellectual doors open” (Papert & Harel, 1991, p. 3). Therefore, even in digital environments, constructionist learning foregrounds personal excursions, narratives, and aesthetic experiences, where learners’ personal lives become deeply intertwined with computational abstractions (Farris & Sengupta, 2016), as well as working in social spaces that foster collaboration and leverage, rather than ignore intersubjectivity as key elements of the learning experience (Kafai & Burke, 2013; Sengupta et al., 2015).

Research on complex systems in K-12 education has also been influenced by constructionist perspectives. This body of work shows that learners can build upon their agent-level (individual level) intuitions in order to develop deep, multi-level understandings of emergent phenomena through creating and modifying embodied and computational simulations (Dickes et al., 2016; Levy & Wilensky, 2008; Wilensky & Resnick, 1999). This can be greatly facilitated by helping learners represent individual-level interactions and mid-level “events,” and it is by summarising and understanding the relationships between these events over time that even elementary grade children can develop understandings of complex phenomena such as disease spread (Levy & Wilensky, 2008), ecological interdependence (Dickes et al., 2016), and electrical conduction (Sengupta & Wilensky, 2009).
THE LEARNING ENVIRONMENT: GRAFEMOS

Grafemos is a modeling environment where children can design their own expressive symbolic-iconic language based on motifs that are designed and used by Guatemalan Mayan women weavers. Based on the Mayan representational system, the symbols and icons represent elements belonging different categories such as human, animal and plant “agents”, emotions, seasons, time, duration, natural elements, pronouns, and others. Symbols can be grouped differently to represent an intended meaning, with the goal to represent an “event,” and events can be arranged either sequentially (i.e., one event leads to another) or in parallel (i.e., multiple events could be happening at the same time) in order to represent an emergent outcome. As described earlier, prior research demonstrates that such an event-based pedagogy can be effective for helping elementary students understand complex systems (Dickes et al., 2016; Wilkerson-Jerde & Wilensky 2015).

With these symbols, the participants create their own language to create a short story in order to explore relationships and emotions between elements of the story. Modeling in Grafemos is also a communal experience (i.e., all participants create their stories on a single fabric or surface). To design their own symbols and language, children begin by selecting from a library of motifs based on elements used by Mayan fabric weaver-designers in Guatemala, as identified by previous ethnographic research by the first author (Lam-Herrera, 2011). Children then create a combination of the motifs to build their own symbols, eventually creating their own language for modeling a story from their own lives that involves exploring their relationships with their loved ones, as well as modeling ecological interdependence in some form that they can relate to in their everyday lives. They iteratively engage in sharing with peers, teachers and stakeholders and revising their work as needed.

DESIGNING TOGETHER: BEGINNINGS OF A JOURNEY

We have begun a partnership with the Mujeres Tejedoras Ixoq’ Aj Kemola’ Association, who belong to the Maya Kaqchiquel community of Santo Domingo Xenacoj. The first author (Marilu), currently a PhD student in Canada, was born and raised in Guatemala and has a relationship with the women weaver-designers in the Maya Kaqchiquel community dating back ten years. Marilu visited the community for a few days in early 2018, and upon invitation of the elders of the community, worked with five elders and eight children for five days to discuss how they wanted to use and change Grafemos to model stories from their lives, as well as complex issues that they are faced with.

In partnering with the community at this stage of the project, our goal is to follow the criteria for both design-based research (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003; Kelly, Lesh, & Baek, 2014; Sandoval, 2004) as well as methodological Métissage as argued by Lowan-Trudeau (2012). Design-Based Research is ideally suited for the project because it allows us to engage in iterative cycles of design where we incorporate the community’s vision and feedback throughout the project. Methodological Métissage involves recognising Indigenous practices and traditions such as storytelling and symbolising from Indigenous perspectives as critical for teaching, research and the researchers, as well as working with the elders and members of the community during all stages of the research: conceptualising the research questions and study design, conducting the study, and interpreting and analysing data. In this paper, we only present highlights from the initial discussions around Grafemos, and two images of artifacts that emerged from the discussion.

Working with Grafemos involves modeling the target phenomenon (or a story) by first selecting six individual elements or agents that are relevant to the target phenomenon or
story, assigning an image to provide meaning to each element, and then creating different combinations of the elements to model interactions between the agents. Elders and children discussed the importance of plastic contamination as a key issue in their community. Further conversations with elders revealed the deterioration of quality of drinking water, which is a known effect of chlorinated plastic contamination even in Western science (Steffan et al., 1999), is an important issue for the community.

Through intergenerational conversations, the community members identified particular objects (e.g., specific forms of plastic used in everyday life) and actions (e.g., throwing away plastic objects without care) as the “agents” and “actions” that lead to contamination. In their Grafemos model, these agents and actions were represented iconically (See Figure 1). The community members also spatially represented a map of their community on the chart paper, where they used Grafemos to imprint their model selection (See Figure 1). This map included relative locations of drainage tubes, the public school, the village market and an overall geographical boundary of their community. As the group began to imprint their model, they explained that the emergence of contamination resulted from the use and discarding of the different elements of plastic which would accumulate in the drainage system. The group noted to Marilu that being able to work with elders and younger members on these issues would give them opportunities to think about both what each individual can do in their daily lives to help reduce contamination, as well as how they could come together as a community to address this issue. They reflected that working with Grafemos could help them visualise the overall (i.e., emergent) effect of their individual actions in terms of reducing contaminants in the community. We believe that this is similar to the notion of multi-level reasoning used by Western scholars of complex systems education, including some of our own previous work (e.g., Wilensky & Resnick, 1999; Dickes et al., 2016). The intergenerational group further argued that the introduction of handwoven fabric and napkins instead of plastic bags and containers could potentially reduce the contamination.

In future visits, we hope to engage in deeper conversations with the community members to co-design ways of engaging in modeling with Grafemos that further integrates the traditional craft of fabric design (as noted by some community members), as well as co-designing analytic frameworks for looking at the discourse during modeling. This partnership can help us identify more clearly synergies and relationships between the noticings of both individual level actions and emergent outcomes by the community members, and commonly used frameworks for analysing multi-level explanations in Western scholarship of complex systems (e.g., Dickes et al., 2016).

Figure 1 – Grafemos Model of Plastic Contamination
CONCLUSION

In this paper, we have presented an argument that Indigenous motifs and traditional forms of representation can serve as productive anchors for designing toolkits and languages for modeling complex systems. We also suggest that positioning Indigenous communities as authoring partners can create opportunities for identifying critical socio-ecological issues within the community, as well as grounds for working together towards potential solutions.

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DEVELOPING AN ABSTRACT UNDERSTANDING OF UNIT ITERATION THROUGH PROBLEM SOLVING

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ABSTRACT

Unit iteration is an important process in understanding and applying area measurement. However, results from large-scale assessments of middle school students’ mathematical achievement indicate that applying unit iteration to solve real-world problems poses significant difficulties for many students. This study investigated how middle school students’ abstract understanding of unit iteration might develop through problem solving. Design-Based Research was used to implement a series of problems designed to elicit students’ abstract understanding of unit iteration. Data from audio-transcripts and copies of student work from two Grade 8 Mathematics classes (n = 31) were analysed to determine the methods and strategies that students used to solve the problems. The findings suggest that students’ abstract understanding of unit iteration developed through solving the area measurement problems posed in this study. Furthermore, it was discovered that problem-solving strategies provided students with the leverage through which their conceptual understanding developed.

Keywords: Area measurement, unit iteration, teaching through problem solving

INTRODUCTION

Area measurement is a core topic in mathematics around the world, principally so that students learn to use the system of quantifying many aspects of everyday life and work, as well as in STEM disciplines. Students typically begin learning the fundamental concepts and processes of area measurement throughout elementary school (Australian Curriculum Assessment and Reporting Authority[ACARA], 2018; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). In particular, learning to iterate and count square units is a fundamental process in understanding area measurement typically taught in the early years (Battista, 2007). When students reach middle school, however, they are expected to have an abstract understanding of the process of unit iteration, that is, they are able to reason about the number of square units covering a space without actually covering a space with square units (Battista, 2007).

Large-scale assessments of mathematical achievement in both the US and Australia indicate that many middle school students struggle to reason about unit iteration. Generally, middle school students in the US and Australia could find the area of a space by counting units, suggesting a basic understanding of unit iteration (ACARA, 2015; Blume, Galindo, & Walcott, 2007). Conversely, students in both countries were generally unable to solve worded problems requiring them to find the number of square tiles needed to cover a given space. These results suggest that middle school students generally lack an abstract understanding of
unit iteration. Furthermore, these results suggest that middle school students also lack the problem-solving strategies necessary to solve a routine application of unit iteration.

There is substantial literature about how teachers might support elementary students’ understanding of unit iteration, however relatively less is known about how teachers might support the development of middle school students’ abstract understanding and application of unit iteration (Battista, 2007). The purpose of the present study, therefore, was to investigate how students’ abstract understanding of unit iteration might be developed through problem solving. To frame this study, I first review the research related to students’ understanding of unit iteration. Following this, I present a theoretical framework for the teaching through problem solving approach to developing students’ conceptual understanding.

LITERATURE REVIEW

Unit iteration is the process of covering a space with identical area units, without gaps or overlaps, and then counting those units to determine the area of the space. In elementary school, students might be given the opportunity to use concrete tiles to cover a rectangle, and then count those tiles to determine the area (Battista, 2007). Alternatively, students might be asked to draw tiles onto a rectangle to represent the iteration of units (Outhred & Mitchelmore, 2000). Regardless of the method used, the purpose of such activities is to elicit students’ understanding of arrays, that is, the number of units needed to cover a rectangle is equal to the number of units along the length multiplied by the number of units along the width.

In addition to teaching children how to structure and enumerate arrays, iterating units mimics many real-world applications of area, such as tiling a floor or painting a wall. To solve such applications, students must have an abstract understanding of the process of unit iteration because counting the number of units across large spaces is unfeasible. Battista (2007) proposes that the complex process of abstracting unit iteration for area involves four stages. Of interest in the present study is the fourth and final stage:

**Stage 4, numerical measurements become symbols.** Mental models of structured unit iterations are raised...so that the resulting enumerations become symbols. That is, numbers, construed as measurements, act as symbols for the unactualized process of iteration. This enables students to meaningfully reason about measurements without iterating units. (Battista, 2007, p. 902)

Battista’s Stage 4 implies that students’ have an abstract understanding of area unit iteration when they can solve area measurement problems using numbers and formulae instead of physically iterating units. Applying the process of unit iteration to solve area measurement problem requires that students develop a connection between the numerical results of using area formulae with the geometric array of units they have calculated (Tan Sisman & Aksu, 2016). Furthermore, the use of division to determine the number of units that will cover a space is indicative of an abstract understanding of unit iteration. To support students in sustaining the connection between area formulae and unit iteration, Strutchens, Martin, and Kenney (2003) argue that students should be given opportunities to count the number of units that cover a space, as well as apply area formulae in realistic contexts. However, research about the effects of such approaches on developing students’ understanding of area formulae and unit iteration is scarce. The overarching research question in the present research was therefore: How does students’ abstract understanding of unit iteration develop through problem solving?
THEORETICAL FRAMEWORK

Teaching through problem solving is a pedagogical approach in which students’ understanding of mathematical concepts and problems-solving competence develop simultaneously while solving mathematical problems (Schroeder & Lester, 1989). Epistemologically, teaching through problem solving is underpinned by constructivism, because it is assumed that students’ knowledge and understanding of mathematics is constructed as they solve mathematical problems. Additionally, students’ existing understanding of mathematics forms the foundation upon which they construct new knowledge through problem solving (Schroeder & Lester, 1989).

There are numerous conceptualisations of teaching through problem solving in the literature. The teaching through problem solving theoretical framework used in this study is comprised of five principles: (1) students’ learning is triggered when the teacher poses a problem; (2) students are given time to make sense of the problem, and struggle with the mathematics that underpin a solution; (3) the role of the teacher is to provide support to students while they are solving the problem while preserving their productive struggle; (4) the teacher facilitates the exploration of multiple methods and strategies used to solve the problem; and (5) the teacher adopts a long-term perspective on developing students’ conceptual understanding and problem-solving strategies.

METHODOLOGY

Participants
Two classes of Grade 8 students (n = 31; mean age = 13.75 years) from a large, high-socioeconomic school in Australia participated in the study. These students’ most recent experience with area measurement was deriving the area formulae for rectangles, parallelograms, and triangles in Grade 7, the previous year.

Research Design
This study employed a Design-Based Research method (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003), which facilitates the experimentation of new approaches to teaching mathematics in a naturalistic setting that contributes to both theory and practice. I was both teacher and researcher in this study and collected data from two sources. The first source was transcriptions of audio-recordings of discussions amongst pairs and triads of students sitting together in a row, one-on-one interviews between myself and individual students, and whole-class discussions. The second source of data was copies of the students’ work.

Activity and Implementation
I designed six problems to elicit students’ abstract understanding of unit iteration. These problems, however, formed part of a larger project that investigated how students’ understanding of area formulae develops through problem solving. Table 1 contains the overall sequence of lessons in the project, and shows when in this sequence of lessons I posed the problems designed to develop students’ understanding of unit iteration. I was the regular Mathematics teacher for both Grade 8 classes participating in the study and implemented these problems-solving activities over five 55-minute periods for both classes.

Retrospective Analysis
I used content analysis (Patton, 2002) to code and categorise the methods that students used to solve the problem and any problem-solving strategies used. The following section presents the results of this analysis.
<table>
<thead>
<tr>
<th>Lesson Topic</th>
<th>Unit iteration problem</th>
</tr>
</thead>
</table>
| Rectangles and composite rectangles | Living room tiling problem  
*Lee is re-tiling her living room floor, which has a length of 6.2 m and a width of 4.5 m. The tiles she chose are 30 cm x 30 cm. How many tiles will she need to cover the living room floor?* |
| Squares               | Paper tile problem  
*Draw a 49 cm² square, and determine how many 4 cm² tiles are needed to cover the square.* |
| Parallelograms        | Glass panels problem  
*The rectangular glass panels used to cover the façade of an office building are 3.98 m high and 10 m wide. How many glass panels would have been used to cover the façade if its area is 1671.6 m²?* |
| Triangles             | -                                                                                                                                                       |
| Composite shapes      | Turf problem  
*Jessica wants to re-turf her backyard. Turf is sold in packs of 4 square tiles, 50 cm x 50 cm. How many packs will Jessica need to re-turf her backyard?* |
| Rhombuses             | Carpet problem  
*Kady selected the following carpet tiles for her new computer room. The tiles are sold in boxes of 10, costing $80 per box.* |
|                       | The following is a diagram of her new computer room.                                                                                                                                                           |
|                       | ![Diagram of computer room](image)                                                                                                                                                                          |
|                       | *Calculate how much it will cost Kady to carpet her new computer room.*                                                                                                                                        |
| Trapezia              | Fertiliser problem  
*Jenny is going to fertilise her trapezium-shaped garden, as shown. Each bag of fertilizer, costing $11.95, contains enough to cover 3 m². How much will it cost Jenny to fertilise her garden?* |
|                       | ![Diagram of trapezium garden](image)                                                                                                                                                                      |
RESULTS AND DISCUSSION

Methods used to solve problems

The analysis of the students’ responses to the Living room tiling problem indicated that only 29% (n = 31) of students solved the problem by dividing the area of the living room (27.9 m²) by the area of one square tile (0.09 m²). However, 3 of these students did not accurately convert the dimensions of the tiles from metres to centimetres, and therefore obtained an incorrect answer. The remaining 71% of students accurately calculated the area of the living room floor but did not understand how to determine the number of tiles. The results of the living room tiling problem suggested that this problem did not elicit the process of unit iteration by the majority of students. However, after students who solved the problem presented their solutions to the class, the remainder of students appeared to understand the use of division to determine the number of tiles. For example, Jodie asked, “Will division always tell you how many units you will need?”.

As a consequence of the retrospective analysis of the results of the living room tiling problem, I designed and posed the paper tile problem in the next lesson.

![Figure 1: Paper tile problem–Sonia’s method.](image)

For the Paper tile problem, I provided 1 cm² grid paper to support the students’ understanding of the connection between unit iteration and the space-covering property of the square 4 cm² tiles. All the students (n = 31) accurately solved the problem, and two different methods were used. The first method, used by 84% of students (n = 31), was to divide 49 cm² by the area of the paper tile (4 cm²). This use of division is consistent with an understanding of the process of unit iteration at an abstract level. Melissa’s response, reproduced in Error! Reference source not found., illustrates this method. The remaining 16% of students counted the number of squares tiles. Note also that all students rounded the number of tiles to 13, indicating that only whole tiles might be possible.
In the remaining four problems, all students (n = 31) used division to determine the number of units required to cover a façade of a building with glass panels (Glass panels problem), backyard with turf (Turf problem), a computer room floor (Carpet problem), and a garden (Fertilizer problem). This result suggests that the majority of students in this study developed an abstract understanding of unit iteration after being given an opportunity to use grid paper to connect the space-covering properties of units with unit iteration. Furthermore, the exploration of multiple methods of solving the problem appears to have elicited further conceptual understanding about the use of division of to determine the number of units—consistent with principle 4 of the teaching through problem solving theoretical framework outlined above.

**Problem-solving strategies**

As noted in the introduction, large-scale assessments of mathematical achievement suggest that middle school students also lack the problem-solving competence required to solve real-world unit iteration application problems. There were two strategies that students used while solving the problems in this study. In 35% of responses, students used a diagram to make sense of the problem and represent their reasoning visually. The most frequently used problem-solving strategy—used in 77% of responses (n = 155)—was the subgoals strategy. The subgoals strategy is defined in this study as the process of breaking a problem down into discrete, separate parts that can be used to achieve the final goal. The subgoals strategy was a critical strategy for most students in solving the unit iteration problems.

This finding suggests that competence in the use of problem-solving strategies, such as the draw a diagram and subgoals strategies, provided leverage in solving the problems that lead to development in students’ abstract understanding of unit iteration. In other words, the mechanism through which the students developed their new understanding was, in part, due to their competence in the use of problem-solving strategies. There is little research about the interaction between the development of conceptual understanding and problem-solving strategies in problem solving contexts (English & Gainsburg, 2016). From a theoretical perspective, the findings of the present study shed some light on the interaction between conceptual understanding and problem-solving strategies within the teaching through problem solving framework.

**CONCLUSION**

This study revealed that the use of division to determine how many units are required to cover a given space is not straight-forward for all students—a finding that echoes the results of many large-scale assessments of middle school students’ mathematics achievement. The
principal finding of the present study, however, was that the Grade 8 students’ in this study
developed an abstract understanding of unit iteration—using division rather than actually
counting units (Battista, 2007) — through problem solving. Instead of the teacher
demonstrating how to use division to determine the number of square units needed to cover a space, the students in this study developed this understanding through solving a series of
authentic area measurement problems.

This finding supports the argument put forward by Strutchens et al. (2003) that in
practice, students be given opportunities to develop their understanding of area measurement
in realistic contexts. A secondary discovery made through the course of this study was that
problem-solving strategies, particularly the subgoals strategy, provided the leverage through
which many students were able to solve the problems that led to the development in their
conceptual understanding of unit iteration. This finding has the potential to advance the
existing literature about the teaching through problem solving theoretical framework.

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POLYÀ'S PROBLEM SOLVING CYCLE AS A BOUNDARY OBJECT FOR THE STEM DISCIPLINES' INQUIRY PROCESSES

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ABSTRACT
This is a discussion paper about integrating the STEM disciplines’ problem solving processes under Pólya’s four problem-solving principles. Each STEM discipline’s inquiry process is presented, and the concepts of boundary crossing and boundary object are used to frame a discussion on how to integrate the STEM problem-solving processes into a boundary pedagogy. Interpreting Pólya’s problem-solving cycle as a boundary object is presented as matrix table which consequently is modified as a template for research purpose. Possible STEM boundary research approaches are proposed at the end to stimulate thoughts on this research agenda.

Keywords: Problem-solving, STEM integration, inquiry process, boundary crossing, boundary object, pedagogy

INTRODUCTION

STEM (Science, Technology, Engineering and Mathematics) Education is an educational enterprise where the four academic knowledge domains (disciplines) meet and where different pedagogical orientations (project-based learning, inquiry-based learning, problem-based learning, etc.) have been employed trying to make connections among the domains. These four knowledge domains are not completely aliened from each other as they are rooted in the logical/mathematical soil and have comparable acts of thought.

A perspective to research STEM education would be to investigate how to pedagogically cross the boundaries between these four knowledge domains. The purpose of this discussion paper is an exploration on how to approach this research agenda. The inquiring and thinking processes of S, T, E and M will be presented and the concept of boundary object will be used to build a proto boundary crossing pedagogy canopying these four processes. Such pedagogy will be suggested to use as an instrument to design STEM classroom research aiming to shape a pragmatic boundary crossing STEM pedagogy that could be implemented in school curricula.

INTEGRATED STEM PEDAGOGY

Burrows, Oehrtman, and Lawson (2006) discussed an integrated learning framework for STEM learning to address
the need for an overarching learning framework that elucidates the commonalities, the distinctions, and the relationships between the learning and practice of mathematics, science and engineering. (ibid.)

The authors proposed a representation of the mutual influences of the concept structures of mathematics, science, and engineering. It is a triad having apexes Mathematical Concept Structure, Scientific Theory Structure and Engineering Design Heuristic Structure.
with annotated both way arrows connecting them. For example, the Mathematical Concept Structure to Engineering Design Heuristic Structure arrow refers to “application of mathematical concepts as tools to draw inferences about engineering design contexts” (ibid.) The framework aimed to illustrate the complexity in integration of instructions for these three STEM fields. The authors suggested that school teachers should engage in long-term professional development in relating the nature of mathematics, science, and engineering practice to prepare students for STEM undergraduate programme.

STEM integration may take different forms: disciplinary, multidisciplinary, interdisciplinary, transdisciplinary, and even meta-disciplinary. English (2016) advocated that if we are to advance STEM integration and lift the profile of all of its disciplines, we need to focus on both core content knowledge and interdisciplinary processes…. strong STEM agendas have well-developed curricula that concentrate on twenty-first century skills including inquiry processes, problem-solving, critical thinking, creativity, and innovation as well as a strong focus on disciplinary knowledge. (ibid. p.3)

Kelly and Knowles (2016) defined integrated STEM education as

the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning. (ibid., p.3)

They proposed a conceptual framework for integrated STEM education presented by a block and tackle of four pulleys (the four STEM disciplines) to lift the load “situated STEM learning”. The pulley system is driven by Community of Practice where participants co-learn the “STEM languages” and STEM practices.

These different proposals use different metaphors to illustrate an epistemic dynamic connectivity that exists among the STEM disciplines. It is commonly accepted that STEM leaning is usually situated in the context of problem-solving. Different STEM disciplines have their own “problem-solving process”. As explicated in the literature mentioned above, investigating the commonalities and differences of the STEM disciplines’ process behaviours is a key to open the door of integration. The rest of the paper will focus on the interdisciplinary processes of problem solving.

PROBLEM SOLVING

In John Dewey’s classic work "How We Think", a Complete Act of Thought was laid out in five logically distinct steps which formed the basis of scientific inquiry and problem solving.

(i) a felt difficulty; (ii) its location and definition; (iii) suggestion of possible solution; (iv) development by reasoning of the bearings of the suggestion; (v) further observation and experiment leading to its acceptance or rejection; that is, the conclusion of belief or disbelief. (Dewey, 1910; p.72)

In the same vein, the Hungarian mathematician George Pólya in his classic work “How to Solve It” proposed four in-step principles when solving a mathematical problem (Pólya, 1945):
(i) Understand the problem,  
(ii) Make a plan,  
(iii) Carry out the plan,  
(iv) Look back on your work. How could it be better?

Many heuristics were suggested by Pólya to carry out the problem-solving steps and these principles are generic to solve different kinds of problems, not just mathematical ones.

For the four STEM disciplines, each have inquiry/problem solving cycle similar to Pólya’s that drives the discipline’s knowledge acquisition process. The following is a summary.

**Science: Scientific Inquiry**

Inquiry-based learning has always been the main constructivist pedagogy in science education. It is a Problem-based teaching and learning approach. The commonly used Inquiry-based Learning model is the BSCS 5E Instructional Model which consists of five pedagogical phases (Bybee et al., 2006):


Furthermore, the process of a scientific method consists of:


**Technology: Computational Thinking**

Cuny, Snyder and Wing (2010) defined computational thinking as

the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent. (ibid., p. 1)

The thought processes involved can be expressed in terms of the following problem-solving steps (Hoyles & Noss, 2015):

1. Seeing a problem at different levels of detail (Entailing Abstraction)  
2. Seeing tasks in terms of smaller connected discrete steps (Algorithmic Thinking)  
3. Solving a problem involves solving a set of smaller problems (Decomposition)  
4. Seeing a new problem as related to problems previously encountered (Pattern Recognition)

**Engineering: Engineering Design**

Engineering, in the context of secondary and primary schools, can be interpreted as acts that include researching, designing, and producing (see for example, English & Mousoulides, 2011). The engineering design process can be realised in 6-step cycle:

1. Research the problem, identify the need and constraints  
2. Imagine: develop possible solutions  
3. Plan: select a promising solution  
4. Create: build a prototype  
5. Test and evaluate the prototype  
6. Improve: redesign as needed
Mathematical Modelling
Mathematical modelling is a problem-solving process of designing, constructing, analysing, mathematising, verifying, revising, and communicating (Capraro & Slough, 2013; English & Mousoulides, 2011). The process is usually expressed as:

1. Ill-defined real-world problem
2. Transform the ill-defined problem into well-defined mathematical problem
3. Make assumptions to get governing equations
4. Solve the equations to get solution to model behavior validated by real-world data
5. Significant and implication
6. Improvement and revision

All the above problem-solving processes are cyclical in nature and they share similar epistemic sequences which can be subsumed under Pólya’s problem-solving cycle. That is, the Pólya’s problem-solving cycle can be used as an over-arching frame connecting the STEM disciplines’ thought processes.

BOUNDARY CROSSING AND BOUNDARY OBJECT

Considering each STEM discipline as a knowledge domain, an integrated STEM pedagogy can be interpreted as a boundary crossing vehicle connecting and making communication between these domains (c.f., Juardak, 2016). When at the boundary between these domains lie compatible epistemological approaches that focus on structured and logical exploration, like Pólya’s problem solving cycle, then it is possible to “translate or transfer” pedagogies between the STEM disciplines via a common boundary object. Boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual-site use. (Star & Griesemer, 1989, p.393)

Pólya’s problem solving cycle fits the description of a boundary object quite nicely. It is generic and plastic enough to adapt to each STEM disciplines and it serves as a common exploration structure which each STEM discipline can commonly identify with.

Pólya’s problem-solving exploration structure is flexible and simplistic, but when it is used in specific STEM domain, it becomes well-structured having complex and rich heuristics.

Table 1 is an attempt to build Pólya’s problem solving cycle as a boundary object. Under each Pólya’s problem solving phase, the corresponding STEM disciplines’ problem-solving phases are listed for comparison and contrast. This table will be used as a template to research boundary pedagogy at the boundary of the STEM disciplines.
Table 1. Pólya’s problem solving cycle as a boundary object

<table>
<thead>
<tr>
<th>Pólya Problem Solving Cycle</th>
<th>STEM Disciplines Inquiry, Problem Solving Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Science (Inquiry-based Learning)</td>
</tr>
<tr>
<td>Understand the Problem</td>
<td>Research the problem; Engage; Explore</td>
</tr>
<tr>
<td>Make a Plan</td>
<td>Postulate a hypothesis; Explain; Elaborate</td>
</tr>
<tr>
<td>Do the Plan</td>
<td>Test with an experiment; Elaborate, Evaluate</td>
</tr>
<tr>
<td>Check Solution</td>
<td>Procedure working? Evaluate</td>
</tr>
<tr>
<td>Modification or Extension</td>
<td>Other better alternative hypotheses?</td>
</tr>
</tbody>
</table>

**BOUNDARY PEDAGOGY RESEARCH**

The basic research question is to explore students’, or teachers’, generation of problem-solving processes and heuristics for STEM-related problems guided by Pólya’s problem-solving cycle. Data obtained are analysed and triangulated with the STEM disciplines’ problem-solving processes discussed above to see whether generalisable cross boundary heuristics occur under the Pólya’s problem-solving cycle. Such finding would shape a STEM boundary pedagogy that possesses the characteristics of a boundary object, and hence form a channel of communication between the instructional practices of the STEM disciplines.

One research approach is to have teachers design a STEM-related problem and a sequence of lessons according to Pólya’s problem-solving phases, one lesson for each phase.
Students, divided into groups, go through the phases consecutively and for each phase they are asked to produce detailed report for their problem-solving processes. Table 2 is a checklist that may be useful for basic benchmarking for this purpose.

Table 2. STEM Problem-solving Checklist

<table>
<thead>
<tr>
<th>STEM Problem Solving Checklist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand the Problem</td>
</tr>
<tr>
<td>☐ Research the problem</td>
</tr>
<tr>
<td>☐ Engaging</td>
</tr>
<tr>
<td>☐ Exploring</td>
</tr>
<tr>
<td>☐ Solving a problem involves solving a set of smaller problems</td>
</tr>
<tr>
<td>☐ Seeing a new problem as related to problems previously encountered</td>
</tr>
<tr>
<td>☐ Seeing a problem at different levels of detail</td>
</tr>
<tr>
<td>☐ Real world problem to well-defined mathematical problem</td>
</tr>
<tr>
<td>☐ Others</td>
</tr>
<tr>
<td>Make a Plan</td>
</tr>
<tr>
<td>☐ Make assumptions</td>
</tr>
<tr>
<td>☐ Postulate a hypothesis</td>
</tr>
<tr>
<td>☐ Explain</td>
</tr>
<tr>
<td>☐ Elaborate</td>
</tr>
<tr>
<td>☐ Seeing tasks in terms of smaller connected discrete steps</td>
</tr>
<tr>
<td>☐ Solving a problem involves solving a set of smaller problems</td>
</tr>
<tr>
<td>☐ Seeing a new problem as related to problems previously encountered</td>
</tr>
<tr>
<td>☐ Seeing a problem at different levels of detail</td>
</tr>
<tr>
<td>☐ Develop possible solutions</td>
</tr>
<tr>
<td>☐ Select a promising solution</td>
</tr>
<tr>
<td>☐ Formulate mathematics equations</td>
</tr>
<tr>
<td>☐ Others</td>
</tr>
<tr>
<td>Do the Plan</td>
</tr>
<tr>
<td>☐ Test with an experiment</td>
</tr>
<tr>
<td>☐ Elaborate</td>
</tr>
<tr>
<td>☐ Evaluate</td>
</tr>
<tr>
<td>☐ Construct a chosen algorithm</td>
</tr>
<tr>
<td>☐ Build a prototype</td>
</tr>
<tr>
<td>☐ Do the mathematics</td>
</tr>
<tr>
<td>☐ Others</td>
</tr>
<tr>
<td>Check Solution</td>
</tr>
<tr>
<td>☐ Evaluate</td>
</tr>
<tr>
<td>☐ Does the procedure work?</td>
</tr>
<tr>
<td>☐ Execute and check the outcome of the algorithm</td>
</tr>
<tr>
<td>☐ Test and evaluate prototype</td>
</tr>
<tr>
<td>☐ Does the solution model the real-world phenomenon?</td>
</tr>
<tr>
<td>☐ Validation by real world data</td>
</tr>
<tr>
<td>☐ Others</td>
</tr>
<tr>
<td>Modification or Extension</td>
</tr>
<tr>
<td>☐ Other better alternative hypotheses?</td>
</tr>
<tr>
<td>☐ Other better alternative algorithms?</td>
</tr>
<tr>
<td>☐ Other better alternative mathematical solutions or models?</td>
</tr>
<tr>
<td>☐ Improvement and redesign</td>
</tr>
<tr>
<td>☐ Others</td>
</tr>
</tbody>
</table>

The mixing up of the STEM disciplines’ elements in the checklist is intentional as these heuristics are expected to appear in diverse combinations in students’ problem-solving processes. Students’ final solutions to the problem are shaped under their problem-solving processes and a major discussion would be how these solutions reflect the STEM disciplines in diverse fashions. Solutions that are hybrids of at least two STEM disciplines are anticipated to contribute to the building up of a cross boundary pedagogical framework.

Another approach would be to gather teachers of the STEM disciplines to form a community of practices. Using Pólya’s problem-solving cycle as a base for cross boundary discussion, teachers develop a common “STEM language” among themselves to design problem-based STEM lessons and to implement them at their own schools, going through cycles of action research.

The above two approaches could go together to ensure that student perspective and teacher perspective are well balanced and synergetic. Once a proto-type boundary pedagogy
is in shape, a next possible research direction is to see whether the boundary pedagogy is applicable to teach specific topics in different STEM disciplines, or to teach the same concept, for example linearity, in different STEM disciplines.

A third approach is to have teachers from different STEM disciplines to teach the same concept, for example ratio and scaling, on their own using the usual discipline practices under a problem-based approach. The intended and implemented lessons are then compared to sieve out critical features that might possibly contribute to the formation of a cross-boundary problem-solving process.

This process is checked against the Pólya’s problem solving cycle to conceptualise a pragmatic boundary crossing approach that teachers can use to teach the same topic. The teachers are then invited to take the same concept to different classes using the newly developed boundary crossing approach. The approach taken may not be exactly the same for each teacher as each teacher should maintain the integrity of his/her discipline, but it would expand the process of inquiry to a broader and more comprehensive pedagogical environment. In this way, a teacher could develop his/her own STEM boundary pedagogy without being an expert of another STEM discipline.

SIGNIFICANCE

One of the major difficulties in STEM education integration is that teachers from different STEM disciplines, understandably, usually have difficulty communicating with each other. Having a common artefact (Problem-solving strategy), acting as a boundary object, will alleviate the teachers’ academic tension between the content subjects.

Furthermore, problem-solving skill is a critical 21st century skill that should be advocated in major curriculum decision. Advanced digital technology is a driving force in current STEM education research, but students need to learn how-to-learn in ways that technology cannot emulate. Learning problem-solving skill is a way of learning how-to-learn. Furthermore, developing a STEM boundary pedagogy is a significant contribution to cross-disciplinary teaching and learning. Such a pedagogy could germane further that includes other non-STEM disciplines, for example Arts, hence STEAM education.

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ABSTRACT

Students’ interest in science learning has been declining in the past few decades. Many researchers proposed that the decline was primarily due to the lack of motivation. This study investigates whether magic tricks can be implemented as Tools to improve students’ motivation in science learning. This is an ongoing small-scale qualitative research study and it is triangulated with the adoption of three-round interview and observation. The research is situated in an interpretivist paradigm. Six 16 to 18-year-old students who study at mainstream schools in London and Cambridge are involved in this study. The interviews and observational data are thematically analysed and micro-expression analysis is adopted for assisting the analysis of observational data. Therefore, the research is informed by two data sources; the interview data carries more weight in the data analysis with the observational data offering explanatory power and enriching the interview data. It is hoped that this study will contribute to the field of students’ motivation in science learning and provide pedagogical suggestions.

Keywords: Motivation in science learning, case study, three-round interview, observation, Tools, triangulation

INTRODUCTION

This paper summarises an ongoing qualitative research study which is an investigation into English secondary school students’ motivation in science learning. This study focuses on whether magic tricks could be implemented as tools for improving students’ motivation in science learning. Drawing on this study, a critical position on the use of magic tricks in science learning is developed.

THEORETICAL FRAMEWORK

This chapter aims to offer a theoretical framework for the present study by demonstrating some of the key foci of the present study.

Understanding Science Learning

It is essential to clarify what science means here and what kind of learning I am investigating. “Science” can be understood and interpreted in different ways. Taber pointed out that it is “centrally concerned with the teaching and learning of, and about, science and the scientific disciplines” (2014, p. 1839). He argued that “learning Science is an active process of constructing personal knowledge” (Taber, 2009, p. 125). In this study, science is applied with reference to what is being defined in the national curriculum in England: “a high-quality science education provides the foundation for understanding the world through the specific disciplines of biology, chemistry and physics” (Department for Education, 2015).
Motivation

Students’ interest in science learning has been declining over the past few decades. It is argued that the decline was mainly due to the lack of motivation (Osborne, Simon & Collins, 2003). Many researchers have reported that students’ motivation could influence their science learning in various ways; the lack of motivation could be resulting from poor classroom environment (extrinsic motivation), or solely from the idea of “I do not want to learn science” (intrinsic motivation). The reason behind this is that many students feel the lack of relevance of the science taught in the curriculum to the real world that we live in (Osborne et al., 2003). As the example of applying theoretical knowledge to the real-life situation, some of the magic tricks are based on scientific knowledge. This research aims to explore whether these can help students improve the motivation in science learning.

In the existing literature, well-researched methodological rationale and data analysis frameworks have been reported in studies of motivation in science learning, mathematics learning and second language acquisition. Surprisingly, emotion, as one of the most influential factors linking with motivation, has rarely been considered by researchers in this field.

We express emotions in verbal and nonverbal ways through voice, body language and facial expressions; it has been empirically proved that there are six basic emotions which share the universal facial expressions, namely fear, anger, disgust, surprise, sadness and happiness (Ekman, 2012; Jiang, 2016). Since these emotions are not only biologically determined but also socially influenced, they might be consciously or unconsciously repressed by us so that we can “behave properly” on many occasions.

To help researchers reveal participants’ true emotions, the concept of micro-expression (the facial expression that involuntarily occurs within a fraction of a second) has been introduced (Jiang, 2016). By analysing the micro-expressions, researchers could have a deeper understanding of learner motivation; hence relatively fine-grained and reliable data would be obtained.

Tools and Mediation

“Human mind is mediated” (Lantolf, 2000) is a fundamental concept which is tied to sociocultural theory. Vygotsky proposed that Tools serve the “mediating role in human reaction and interaction with the world” (Verenikina, 2010, p. 19). Tools can be categorised as external/physical tools (e.g. artefacts, instruments, etc.) and internal/psychological/symbolic tools (e.g. procedures, methods, concepts, etc.). External tools are designed to “manipulate physical objects”, and internal tools can be used for learners to “influence people or themselves” (Verenikina, 2010, p. 19).

In particular, Ausubel (2000) proposed that “advance organiser” is a kind of symbolic tool which can support learning. An advance organiser is “a pedagogic device that helps implement these principles by bridging the gap between what the learner already knows and what he needs to know if he is to learn new material most actively and expeditiously” (Ausubel, 2000, p. 11); therefore, the advance organiser is designed to support mental scaffolding, so that learners can relate the new things that they are learning to the existing knowledge.

In the present study, this refers to how the learner relate what he or she has gained from the magic tricks to the science curriculum with sophisticated metacognitive awareness. Besides, it is argued that mediation takes place vicariously through the use of external tools and internal tools. Therefore, humans can use external and internal tools to mediate their
relationships with the broader social context and the world. In this study, the magic tricks are theorised as Tools in science learning.

**Research Question**

1. What motivational factors do secondary school students report when learning science in out-of-class contexts?
2. How the use of magic tricks influence students’ motivation in science learning?

**METHODOLOGY**

**Interpretivist Approach**

The research is situated in an interpretivist paradigm. The interpretivist view “emphasises how people differ from inanimate natural phenomena and, indeed, from each other” (Cohen, Mannion & Morrison, 2007, p. 7), and it is an approach often used to describe individual and social behaviour. Researchers who adopt the interpretivist paradigm often construct their understanding through participants’ perceptions and experiences (Creswell, 2009; Schwartz-Shea & Yanow, 2012). Interpretivism, therefore “supported scholars in terms of exploring their world by interpreting the understanding of individuals” (Thanh & Thanh, 2015, p. 24). Interpretivist research is consistent with a constructivist perspective on student thinking and learning.

**Case Study**

This study adopts a case study methodology as the case study “enables the researchers to answer ‘how’ and ‘why’ type questions while taking into consideration how a phenomenon is influenced by the context within which it is situated” (Baxter & Jack, 2008, p. 556). In addition, the case study “offers significant benefits for those seeking to develop theory in new, largely unexplored areas” (Torraco, 2002, p. 371). This study focuses on the use of magic tricks as Tools in science learning, which is a relatively “new” and relatively “unexplored” area. Therefore, this research adopts a case study methodology, aiming to explore students’ science learning with magic tricks in informal contexts. It is hoped that new insights could be provided and contributions could be made to this field.

**Case Selection**

Thirteen 13 to 18-year-old students who study at mainstream schools in London and Cambridge are involved in this study. As students in post-16 years learn Physics, Biology and Chemistry separately, it is possible that some of those taking one of these subjects may also take others therefore at least two students who learn Physics, two students who learn Biology and two students who learn Chemistry are chosen.

**Data Collection**

This is an ongoing research study; I briefly explain the data collection methods in this section.

**Three-round Semi-structured Interview**

In this study, three-round semi-structured interviews are carried out. The first-round interview aims to get familiar with the participants and to explore the research questions. I start each first-round interview with introductory questions including asking the participant to introduce himself or herself, talking about his or her educational experience, etc.

These questions help to relax the participants, and they are relevant to my research since they could help me establish the thick description of the participants’ educational background. Science Motivation Questionnaire (SMQ) (the copyright is held by Glynn & Koballa, 2006) is also adopted in the first-round interview since it has been considered as a
“reliable, valid, and convenient tool for assessing students’ motivation to learn science” (Glynn, Taasoobshirazi & Brickman, 2009, p. 141).

However, since this is not a quantitative study aiming to figure out the links among different dimensions of learners’ motivation, SMQ is used as a focus for a “think aloud” activity during the interview. I show each participant a number of statements including “Earning a good science grade is important to me”; “I use strategies that ensure I learn the science well”; etc., and I then ask the participant to give his or her answer with comments or examples.

After all the first-round interviews are finished, the interviews are transcribed. I read through the transcriptions; codes, as well as initial themes, are identified. At this point, I could notice dimensions that occur in each of the interviews. However, dimensions occur in some of the interviews might also be the concern of other participants. Therefore, the second-round interview aims to explore whether these dimensions are relevant to those who have not mentioned yet in the first-round interviews. I do not compare among participants at this stage but use the information that I could get from various interviews to help make sure that I could explore the full dimensions of each case.

The aim here is not to “force” issues elicited from one participant onto other, but rather to indirectly allow cross-fertilisation of ideas through indirect social mediation: to test whether concerns of features identified from an individual participant resonates with others, even when not initially brought to mind. After the second-round interviews, I briefly analyse the data to help me decide what to focus during the observations. Then the observations are carried out.

Observation
Observation is adopted as another data collection strategy in this study. A professional magician who is an A.I.M.C. Silver Star member of The Magic Circle (one of the world’s premier magic societies) is invited to help me with the observation. I have filmed three magic tricks performed by him; all these magic tricks have the element of physics and/or chemistry.

Observation in this study could provide me with the opportunity to observe students’ learning experience in out-of-class contexts. Video data from observations are converted to the QuickTime format for fine-grained analysis afterwards. During the observation, the same magic tricks are shown to each participant. Each participant has been asked whether they can relate the magic tricks to any of the scientific concepts. The scientific knowledge behind each magic trick is briefly explained afterwards.

After the observations, the third-round interviews are carried out, serving as the member-check process for the semi-structured interviews as well as the follow-up discussion of the observations. During the third-round interviews, I could discuss my understanding with the participants, to ask them whether my interpretations reflect what they mean. As follow-up discussions, what I have noticed from the observations are discussed with the participants; how the motivation in science learning has been influenced is also discussed. Through this process, richer data can be produced, and the negative influence of subjectivity can be reduced.

Establishing Trustworthiness
It is suggested that triangulation could enhance the credibility, dependability and confirmability of qualitative research (Guba, 1981; Lincoln & Guba, 1985). As mentioned earlier, three-round interviews and observations are adopted in this research; it can be seen that this inquiry is designed in a triangulated way. Regarding dependability, although this study focuses on a particular context, it could be replicated since detailed methodological
descriptions are provided. Adequate background information and database will be provided so that transferability judgements can be made by other researchers.

In addition, peer examination is also included to increase the credibility and dependability of the present research (Guba, 1981; Lincoln & Guba, 1985). I show some of the transcripts to other experienced qualitative researchers to check whether the codes and themes that I interpret are appropriate.

RESULTS AND DISCUSSION

This is an ongoing research study; therefore, the results are yet to come. In this section, I briefly explain the data analysis strategies and report some of the preliminary findings.

Thematic Analysis

The research is informed by two data sources; the interview data carries more weight in the data analysis with the observational data offering explanatory power and enriching the interview data. The thematic content analysis is adopted in this study.

During the coding process, to develop a clear coding strategy in which could serve the purpose of responding to the research questions, the priority is to use participants’ language as codes. I revisit the codes, and some necessary changes might be made via recoding process. To answer the research questions, the codes are then being categorised into themes.

Micro-expression Analysis

Field notes are commonly used for analysing observations. Researchers often note down crucial information in relation to the research questions. Besides, the micro-expression analysis is widely adopted in two fields which are psychological research studies and animations, whereas it has less likely been adopted in educational research.

Since it is argued that reading micro-expressions could enhance emotional awareness, micro-expression analysis can help detect the meaning behind the responses; it should be considered as one of the critical data analysis methods in research studies that involve interviews and observations.

In this research, participants’ micro-expressions are recognised and analysed to explore what their “real” feelings are. Coding and recoding are also carried out for the observational data so that themes could be identified. These codes and themes are then being compared with the codes and themes generated from the interviews.

Preliminary Findings

Research question 1: What motivational factors do secondary school students report when learning science in out-of-class contexts?

Table 1. Motivational Factors

<table>
<thead>
<tr>
<th>Motivational Factors</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enjoyment</td>
<td>“I love science, I am just interested in learning science”</td>
</tr>
<tr>
<td>Career Goal</td>
<td>Science learning is relevant to participant’s career choice</td>
</tr>
<tr>
<td>Examination Anxiety</td>
<td>Learning science for gaining a high score in science examination</td>
</tr>
<tr>
<td>Parental Influence</td>
<td>Participant’s science learning has been influenced by his or</td>
</tr>
</tbody>
</table>
Research question 2: How the use of magic tricks influence students’ motivation in science learning?

It can be concluded that when participants are (not) motivated, certain types of micro-expressions could be recognised; therefore, emotions are linked with motivation. Researchers can adopt the micro-expression analysis to determine whether learners are motivated. When students talk about why they enjoy science learning, micro-expressions which are relevant to the emotion of “happiness” can always be detected. Whereas when students make statements to explain why they are not motivated in science learning, for example, “I really can’t understand physics, just, just too abstract”, micro-expressions which are relevant to the emotion of “disgust” and “fear” can be recognised.

When students watch magic tricks, micro-expressions which are relevant to the emotion of “surprise” and “happiness” can be detected. All the participants agree that these magic tricks do motivate them to learn more scientific concepts and figure out how the tricks could be done.

Ethics
This is a research study that involves children (13–18 years old) as participants, therefore before running the data collection with the participants, data collection and media usage permissions from both participants themselves as well as their guardians have to be required. Furthermore, to protect participants’ privacy, I will blur participants’ faces in the images that I wish to use in the paper. Besides, it is anonymous research as the participants’ names will not be mentioned in the data analysis.

The research follows the revised ethical guidelines for educational research provided by British Education Research Association (BERA). Followed by Diener & Crandall’s (1978) guideline, the participants would not be harmed in this research. To reduce the risk of deception, all the participants are shown the information sheets before they decide whether or not to take part in this study. The information sheet includes a brief research introduction, explaining the purpose of the present study. Then I provide them with informed consent forms to obtain their permissions on recording and the use of the data. All the transcriptions will be anonymous, and all data will be stored in encrypted folders in the laptop which will be kept for future use.

CONTRIBUTION
By conducting the present study, it is hoped that theories in relation to Tools would be understood and developed in the field of magic assisted science learning in out-of-class contexts. Regarding the contributions of this study, firstly, this study could provide some suggestions on how to improve students’ motivation in science learning.

Secondly, this empirically based study investigates accounts of experiences from learners by using interviews and observations, which could provide fruitful information from learners’ perspectives; therefore, pedagogical approaches might be developed.
Thirdly, since SMQ is used for the “think aloud” activities, it is hoped that this would provide insights to the methodological considerations for researchers who will carry out studies in the field of motivation in science learning.

Finally, since micro-expression analysis is adopted, it is hoped that this will open up more opportunities for applying some basic micro-expression analysis strategies in educational research, and to encourage researchers to envisage research methodology and methods from the new angle.

REFERENCES


OVERCOMING BARRIERS: ENROLLMENT IN MATHEMATICS AND PHYSICS AT THE ADVANCED LEVEL IN SECONDARY SCHOOL AMONG TWO GENERATIONS OF HIGH-SKILLED IMMIGRANTS

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ABSTRACT

Applying Bourdieu’s concept of “cultural capital”, this research focuses on enrollment in Mathematics and Physics at the advanced level in secondary school among first and second generations of Former Soviet Union (FSU) immigrants and third generation of Israeli born Jews. Among FSU immigrants, STEM-related education constitutes one of the central cultural values, which they try to transmit to their children. This paper made use of the Israeli Ministry of Education’s database, which include data on all students who finished their secondary education with a matriculation certificate in 2013. Our findings show the initial similarity in enrollment in Physics among FSU first generation and third generation Israeli-born students, which preserved in multivariate analysis. First generation FSU students were less likely to be enrolled in Mathematics at the advanced level compared to other groups. We found an initial advantage of second-generation FSU immigrants, both in Mathematics and Physics, compared to the two other groups. However, after controlling for student and school variables, the second-generation FSU students preserved their advantage only in Physics. In spite of the fact that Physics is considered a more difficult and demanding subject than Mathematics, for FSU boys both generations are more likely to be enrolled in the former. In contrast, the third generation demonstrates the opposite pattern. A possible explanation is the fact that enrollment in Mathematics at the advanced level may reflect more belonging to a privileged social group, while enrollment in Physics at the advanced level may reflect possession of suitable familial cultural capital.

Keywords: High-skilled immigrants; STEM subjects at secondary school; cultural capital; between-generation differences

For sustainable prosperity, developed countries require a scientifically literate population (OECD, 2013) and professional workforce that engages in STEM (Science, Technology, Engineering, and Mathematics) fields. STEM-related careers often offer higher financial payoffs, opening doors to economic upward mobility and financial independence. This is especially relevant for economically and socially disadvantaged groups.

These jobs allow for subjective well-being emphasised in modern societies and may function as a safety-net against modern risks such as unemployment in an unpredictable global market. They are eminently transferable between national contexts as their professionalism is “based on a verifiable set of skills and credentials” that are accepted automatically regardless of context (Remennick, 2013; Yonezawa, Horta, & Osawa, 2016). STEM careers require learning STEM related subjects at advanced levels in secondary education. Nevertheless, these subjects are perceived as incurring large costs in terms of...
difficulty and number of years of study (Tytler, Symington, Kirkwood, & Malcolm, 2008) and are unlikely to be regarded as an ‘easy’ path to a good job or other benefits. As a result of perception of STEM fields as difficult and demanding, disparities exist among population groups, with minorities and women traditionally underrepresented in STEM undergraduate programs and in the STEM workforce (Alon & DiPrete, 2015; Chachashvili-Bolotin, Milner-Bolotin, & Lissitsa, 2016).

The literature on ethnic differences in science enrollment in secondary schools is relatively limited and focused mainly on low-skilled ethnic and racial minorities. To our knowledge, STEM research on high-skilled immigrants based on large-scale data has yet to be conducted. This comparative research evaluates enrollment in science fields (specifically, Mathematics and Physics) at advanced levels in secondary school between first and second generations of high-skilled immigrants and the native population. Israel provides an attractive setting for such a study considering the fact that during the past two decades more than 800,000 immigrants from the Former Soviet Union have immigrated to Israel.

Russian speakers, who are the focus of this study, have a high socio-economic profile in terms of educational level and percentage of professionals compared to the native Jewish population. Moreover, this immigration wave was unique in terms of STEM professionals: over 80,000 engineers immigrated to Israel from the FSU and joined the labour market at the beginning of the 1990s, effectively doubling the stock of engineers in the country (King & Naveh, 1999; Remennick, 2003).

THEORETICAL BACKGROUND AND RESEARCH QUESTIONS

Pierre Bourdieu, conceived of “cultural capital” as the knowledge, skills, and behaviors that are transmitted to an individual within their socio-cultural context through pedagogic action (Bourdieu, 1986). Success in the educational system often requires a predisposed cultural capital gained through family upbringing. Parental human and cultural capital can be transferred to offspring in multiple indirect and subtle ways. These include after-school enrichment activities, secure and pleasant residential milieu, and quality time for parents to spend with their children, contributing to moral education and motivation for success (Kasinitz, Mollenkopf, Waters, & Holdaway, 2009). Accordingly, research indicates positive associations between family support, encouragement, involvement, and student efficacy and learning experiences (Craig, Verma, Stokes, Evans, & Abrol, 2018; Navarro, Flores, & Worthington, 2007).

This is especially the case when cultural capital is relevant to the local educational system and parent occupation can be leveraged in target labour markets and supply decent economic rewards. Engineering as well as technical and scientific occupations are the most convertible in the new labour market. They are less dependent on language proficiency and may serve as a pipeline for occupational and economic mobility (Remennick, 2013). As noted, FSU immigrants were characterised both by highest percent of post-secondary degrees and STEM-related occupations as compared to natives. That is, future STEM related careers for FSU immigrant students enable them to utilise family cultural capital and ensure future economic security.

However, high-skilled FSU immigrants and their children should not be considered as a unitary whole. Many comparative studies on educational achievements of generations of immigrant and native students found that the main predictors of educational achievements for children of immigrants are parental SES and number of years in destination country post-immigration (Alba & Nee, 1997, 2003; Portes & Rumbaut, 1996, 2001; Portes & Zhou, 1993;
Vaquera & Kao, 2012). The findings on differences between the first and second generations of immigrants were equivocal.

For instance, it was found that educational achievements of the second generation are likely to be higher compared to first generation (Alba & Nee, 1997, 2003). However, it was also shown that generational differences may derive more from differences in socio-economic parental background than number of years in destination country post-immigration (Portes & Rumbaut, 1996, 2001; Portes & Zhou, 1993).

Most comparative research focused on educational achievements of generations of low-skilled immigrants and native-born students, but did not focus on STEM subjects. As far as we know, between-generation research on high-skilled immigrants, especially in science fields, has yet to be conducted. As such, this work attempts to fill this void, and in doing so formulates the following research questions:

RQ 1: What between-group differences exist between first and second-generation FSU immigrants and third generation Israeli Jews regarding enrollment in Mathematics and Physics at the advanced level?

Numerous studies have emphasised Mathematics anxiety at all educational levels (Hill et al., 2016). Physics also has a long tradition of being perceived as the most difficult subject, even among high achieving students due to high workload, representational sophistication, high level of abstraction, and unconventional modes of thinking (Krogh & Thomsen, 2005). Moreover, Physics is considered by students to have far less relevance to their everyday lives compared to other STEM disciplines (Bøe, Henriksen, Lyons, & Schreiner, 2013). Accordingly, our second research may be stated as follows:

RQ 2. What between-group differences exist between enrollment in Mathematics and Physics at the advanced level?

METHOD

Database

This research made use of Ministry of Education databases, which include data on all students (not a sample) in the Jewish sector in the two types of schools: state and state-religious. The parents reported information on student background variables during school registration procedures. Our database refers to those students who finished their secondary education with a matriculation certificate (bagrut) in 2013 (most of students were born in 1995), with parents born in Israel or the FSU. Our final dataset included 31,555 third generation Israeli Jewish students, 5,765 second-generation FSU immigrant students, and 2,477 first-generation FSU immigrant students.

Variables

Dependent variables: Enrollment in Mathematics and Physics at the advanced level. These variables were dichotomic, those who did not study the mentioned subjects at the advanced level (5 units) served as the comparison groups.

Student variables: Ethnic origin (first generation of FSU immigrants, second generation of FSU immigrants, and third generation Israeli-born Jews (comparison group)), Gender, Mother’s/father’s education.

School variables: Type of school (state = 0 and state-religious = 1), the number of students in 12th grade at school, the percentage of boys at school, and the average percent of matriculation eligibility at school.
FINDINGS

Descriptive analysis

*Enrollment in science subjects at the advanced level*

Table 1. Percent of enrollment in Mathematics and Physics at advanced level by gender and
generation

<table>
<thead>
<tr>
<th></th>
<th>Third Gen. FSU</th>
<th>Third Gen. FSU</th>
<th>Third Gen. FSU</th>
<th>Third Gen. FSU</th>
<th>Third Gen. FSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girls</td>
<td>12.0%</td>
<td>9.7%</td>
<td>13.1%</td>
<td>19.0%</td>
<td>13.9%</td>
</tr>
<tr>
<td>Boys</td>
<td>13.9%</td>
<td>13.9%</td>
<td>22.0%</td>
<td>13.9%</td>
<td>22.0%</td>
</tr>
<tr>
<td>Physics</td>
<td>6.3%</td>
<td>8.4%</td>
<td>9.4%</td>
<td>18.4%</td>
<td>18.2%</td>
</tr>
<tr>
<td>Both Math and</td>
<td>4.9%</td>
<td>5.5%</td>
<td>7.1%</td>
<td>13.9%</td>
<td>11.4%</td>
</tr>
<tr>
<td>Physics Gap</td>
<td>5.7%</td>
<td>1.3%</td>
<td>3.7%</td>
<td>0.6%</td>
<td>-4.3%</td>
</tr>
<tr>
<td>Math and Physics</td>
<td>4.9%</td>
<td>5.5%</td>
<td>7.1%</td>
<td>13.9%</td>
<td>11.4%</td>
</tr>
</tbody>
</table>

As can be seen (Table 1), among both genders the second generation FSU immigrants had the highest percent of enrollment in studying Mathematics (22% among boys and 13% among girls) and Physics (25% among boys and 9% among girls) at the advanced level, compared to the other two groups. For both genders, enrollment in Physics was similar between first generation FSU immigrants and third generation Israeli-born students. FSU boys from both generations were more likely to be enrolled in Physics than Mathematics, whereas among the third generation the pattern was reversed.

Multivariate analysis

In Tables 2 and 3 we present the parameter estimates of Generalized Linear Mixed Models of enrollment in: Mathematics at the advanced level (see Table 2 ) and Physics at the advanced level (see Table 3). We ran the same models for our dependent variables. Our first model (Model 1) included only gender and ethnicity variables. School variables were added to the second model (Model 2) and our last model (Model 3) included all student and school variables.

Table 2. Predicting the odds of enrollment in Mathematics at the advanced level -Generalized Linear Mixed Models findings

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-2.31**</td>
<td>-4.83**</td>
<td>-4.75**</td>
</tr>
<tr>
<td>Student variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>0.55**</td>
<td>0.55**</td>
<td>0.55**</td>
</tr>
<tr>
<td>First generation</td>
<td>-0.18**</td>
<td>-0.15*</td>
<td>-0.34**</td>
</tr>
<tr>
<td>Second generation</td>
<td>0.20**</td>
<td>0.21**</td>
<td>-0.06</td>
</tr>
<tr>
<td>Mother post-secondary educ.</td>
<td>0.23**</td>
<td>0.34**</td>
<td>0.63**</td>
</tr>
<tr>
<td>Father Post-secondary educ.</td>
<td></td>
<td></td>
<td>0.80**</td>
</tr>
<tr>
<td>School variables</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Our first model (Model 1, Tables 2, 3) replicates the findings of descriptive analyses. Boys were significantly more likely than girls to be enrolled in Mathematics and Physics at the advanced level. Second generation FSU immigrants were more likely to be enrolled in all mentioned subjects at the advanced level compared to third generation Israeli-born Jews.

In contrast, the first generation FSU immigrants were less likely to be enrolled in Mathematics at the advanced level. The differences between the FSU first generation and the third generation in enrollment in Physics at the advanced level were insignificant. Adding school variables to our regressions (see Model 2, Tables 2, 3) revealed an increase in the odds of enrollment in both subjects among the two generations of FSU students.

In other words, the advantage of second-generation students increased, while the disadvantage of first generation FSU immigrants diminished. This can be explained by the fact that immigrant students studied on average in less prestigious schools. The number of 12th grade students at school and the average percent of matriculation at school increased the odds of enrollment in all mentioned subjects (see Tables 2, 3).

Controlling for student and school variables (see Model 3, Tables 2, 3) reveals that student variables (gender and parental education) are more profound compared to school variables. From student variables, the educational level of both parents was the most sufficient variable. As a result of the high level of parental education of FSU immigrants, we found that after controlling for parental education the initial advantage of second generation of immigrant students diminished (enrollment in Physics at the advanced level, see Model 3, Table 3) or disappeared (enrollment in Mathematics at the advanced level, see Model 3, Table 3).
Table 2). A similar pattern was found among first generation FSU immigrant students: controlling for parental education increased their initial disadvantage in enrollment in Mathematics at the advanced level (see Model 3, Tables 2). The earlier advantage of the first generation in enrollment in Physics at the advanced level (see Model 2, Table 3) compared to the third generation was found to be insignificant (see Model 3, Table 3).

DISCUSSION

The current study compared enrollment in Mathematics and Physics at the advanced level in secondary school between two generations of FSU immigrants and third-generation Israeli Jews. Bourdieu’s concept of “cultural capital” was applied.

Our descriptive findings show that for both genders, second generation FSU immigrants had an advantage in percentage of enrollment in studying Mathematics and Physics at the advanced level, compared to the third generation of Israeli Jews and first generation immigrants. The advantage of the FSU second generation compared to third generation Israelis may be explained both by STEM related cultural capital and higher parental education. The advantage of second generation immigrants compared to first generation may be attributed both to higher parental educational background and better family integration in Israel (Alba & Nee, 1997, 2003; Portes & Rumbaut, 1996, 2001; Portes & Zhou, 1993).

Due to greater number of years in the destination country post-immigration, second generation students have better educational opportunities as a result of parental mobility and status, which are accompanied by better language proficiency, higher level of family social integration, and more developed networks. These can supply information and support, more prosperous neighborhood locations with better schools, and economic opportunities.

Comparing first generation immigrants and third generation Israelis, we found that their enrollment rates in Physics were similar. Generally, this similarity can be interpreted as a significant achievement of first generation students, who, in spite of lack of economic means, learning in less prestigious schools, and lower language proficiency, succeeded in a demanding field. This may be attributed to STEM-related cultural capital of student families.

Another possible explanation for relatively high educational achievements among first generation students include lower dependency of science subjects at school on language proficiency and Israeli culture compared to the Humanities. However, it should be noted that enrollment in Mathematics at the advanced level among first generation FSU immigrants was lower compared to the other groups. A possible explanation is low familiarity with the Israeli secondary and tertiary educational system and, in particular, little awareness of Mathematics as a prerequisite of prestigious tertiary education.

Moreover, among the first generation of FSU immigrants, the gender gap in all subjects was less pronounced compared to the second generation and third generation Israelis. We may assume that due to only partial integration of the first generation, they were less exposed to the gender STEM stereotypes. They thus preserved the patterns of gender engagement in STEM-related fields from the FSU. Another possible explanation is the fact that according to the research literature, girls are more likely to overcome immigration difficulties in school integration compared to boys (Berry, Phinney, Sam, & Vedder, 2006). Therefore, the educational achievements of immigrant boys inadequately reflect their potential.

As noted, Physics is considered a more difficult and demanding subject than Mathematics. However, in both generations among FSU boys enrollment is higher in Physics compared to Mathematics. In contrast, the third generation demonstrates the opposite pattern.
In order to reveal the mechanisms of between-group and between-subject differences, we conducted a multivariate analysis integrating student and school variables. As for the enrollment in Mathematics, the advantage of the second-generation FSU students became insignificant. Moreover, the first generation of FSU students became the disadvantaged group. Still, we found a different pattern regarding enrollment in Physics at the advanced level: the second generation preserved their initial advantage, while the gap between first and third generation was found to be insignificant.

Controlling for student and school variables reveals that student variables are more profound in prediction of enrollment in science fields compared to school variables. In line with the research literature (see Portes & Rumbaut, 2001; Portes & Zhou, 1993), from the student variables, parental education was the most sufficient. We found that after controlling for parental education, the initial of second-generation immigrant advantage diminished or disappeared among students (as a result of the much higher level of education of FSU immigrants). That the initial advantage of the second generation remained only in predicting enrollment in Physics may indicate the role of parental cultural capital in educational choices.

A similar explanation may be applied to the first generation: only in Physics was there initial similarity between the two generations and the third generation remained the same in the multivariate analysis. In both other dependent variables, they were found disadvantaged. Summarising our findings, we may argue that among high skilled immigrants, the combination of both high cultural and human capital may partially compensate for lower economic status, worse school environments, and less familiarity with local educational systems.

CONCLUSIONS

Our finding show that in the competitive field of Mathematics, first generation FSU students still suffer from educational barriers. However, in less competitive and more demanding and Physics, a field more dependent on cultural capital, such barriers do not exist. The second generation of FSU students already overcame barriers in the science fields and even mobilised their cultural capital for obtaining the advantage in Physics. A possible explanation for this is the fact that enrollment in Mathematics at the advanced level may reflect more belongingness to a privileged social group than real student capability.

In contrast, enrollment in Physics at the advanced level reflects possession of suitable familial cultural capital, which, due to requirements of STEM tertiary education, may be reproduced only if combined with Mathematics. In this way, the Israeli educational system reproduces social inequality and serves as a barrier for disadvantaged social groups entering prestigious tertiary majors.

Based on our findings, our important recommendation is to increase awareness of studying Mathematics at the advanced level, especially among first generation FSU immigrants. In general, educational policymakers should mobilise all potential resources for overcoming ethnic, gender, and socio-economic barriers for entering Mathematics at the advanced level. Vigorous motivation of adolescents to take science courses will best prepare them for a successful future.

REFERENCES


A STUDY ON AUGMENTED REALITY BASED COMPREHENSIBLE VISUALISATION FOR DEVELOPING STUDENT'S FRICTION CONCEPT

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ABSTRACT

Inquiry-based learning is gaining popularity in science curricula and thus attracts the attention of researchers worldwide. This paper presents the development of an Augmented Reality (AR) based friction experiment system that is established to show students comprehensible visualisation for enhancing student’s friction force concepts, and investigates the effect of embedding AR in authentic inquiry-based friction experiment. Abstract conception visualisation and inquiry-based experiment are two key design principles that motivate the AR based friction experiment, with which students can intuitively observe abstract visualisation of friction through mobile devices and design inquiry-based friction experiment freely. An interview is conducted to evaluate the effectiveness, acceptance and satisfaction of the proposed AR based friction experiment system, which shows that the AR based friction experiment system is more effective than the traditional teaching methods. In the future, the student participant will be invited for additional evaluation experiments on this system.

Keywords: Augmented reality, inquiry-based experiment, comprehensible visualisation, friction concept

INTRODUCTION

Highly qualified Science, Technology, Engineering, and Mathematics (STEM) fundamental science experiments are needed for K-12 science education (Akçayır, Akçayır, Pektaş, & Ocak, 2016). Regarding experiment skills and science conceptualisation, STEM education gives students much help to develop their understanding of basic science conception (Cotabish, Dailey, Robinson, & Hughes, 2013). Envisioned improvements to STEM experiment education include calling for changes towards better integration of the various disciplinary knowledge and skills to provide learning experiences that are meaningful to students with the needs of understanding abstract scientific conceptions (Hsu, Lin, & Yang, 2017). Envisioned improvements to STEM experiment education include calling for changes towards better integration of the various disciplinary knowledge and skills to provide learning experiences that are meaningful to students with the needs of understanding abstract scientific conceptions (Hsu, Lin, & Yang, 2017). The visual intensity of STEM fields arises from representations and models developed to describe natural phenomena (Lamb, Akmal, & Petrie, 2015). Correlational and more recently predictive studies have solidly demonstrated the relationship between STEM achievement and spatial visualisation (Pruden, Levine, & Huttenlocher, 2011). Spatial visualisation reduces students’ cognitive load when engaging in STEM-related tasks through the additional cognitive channels to process data (Gonzalez-Castillo et al., 2012).

AR technology has been gradually applied to various fields since 1990; it can be used as a method presenting additional information using physical operation as a medium, so that users can visually see the integration of the real world and virtual objects (Chang et al., 2014). AR has three main characteristics: (a) combines real and virtual objects in a real
environment, (b) runs interactively, and in real time, and (c) registers (aligns) real and virtual objects with each other (Azuma et al., 2001). AR also makes it possible to visualise abstract concepts such as force or magnetic fields by displaying virtual elements over real objects.

This study established an inquiry-based physical friction experiment system to present students comprehensible visualisation for enhancing student’s force concepts and investigate the effect of embedding AR in authentic friction experiment. By integrating AR technology into STEM lessons design, students can manipulate the experiment device and observe the visualisation of abstract friction in authentic contexts simultaneously. The findings of this paper contribute to an understanding of friction conception for students and how K-12 teachers perceive STEM lessons with AR technology.

The research questions guiding this study are:

1. Is the system established in this paper more effective in developing the student’s concepts of friction compared to the traditional methods at the viewpoint of the teacher?
2. Is this AR based friction experiment accepted by the teacher as a useful experiment mode?
3. Does the teacher get satisfaction from the AR based visualisation and inquiry-based friction experiment system?

The remainder of the paper is organised as follows. In the theoretical framework section, the related theories of comprehensible visualisation and inquiry-based experiment are described. In the methodology section, the proposed AR based friction experiment system is presented in detail. In the results and discussion section, advantages and shortcomings of the proposed system are discussed. Finally, conclusion and future work are provided in the last section.

THEORETICAL FRAMEWORK

The theoretical framework of this study mainly includes two parts: comprehensible visualisation for friction conception and inquiry-based instruction experiment.

It is widely accepted that visualisation is an effective teaching tool. Current applications of visualisation are found in such teaching contexts as mathematics, reading, science and technology (Vavra et al., 2011; Gilbert, 2005; Korakakis, Boudouvis, Palyvos, & Pavlatou, 2012). Visualisation plays a central role in the conduct of science when student learns with multimedia material before AR emerging.

In recent years, with AR based applications implementing at the education domain, visualisation is still one of the most effective method in science education, because the student can easily get the visual additional information that is overlaid on the real world with the help of AR technology. In the AR based experiment system, visualisation of virtual detail information about complex patterns will appear to the viewers, which help them have a better understanding about the complex patterns.

Inquiry-based learning is an educational strategy in which students follow methods and practices similar to those of professional scientists in order to construct knowledge (Pedaste et al., 2015). Rather than forcing students to learn according to a fixed process, students should be encouraged to explore, research, and think about the knowledge they have gained.

In inquiry-based learning activities, teachers must first choose the right research questions and help students develop an appropriate research plan. Then students should raise experimental hypotheses themselves and conduct hands-on research in an open experimental
situation. At the same time, teachers are required to provide certain experimental directions or necessary information to students. Finally, the students themselves can experiment or consult to find the answers to the questions and make certain assumptions. There are many advantages of inquiry-based learning, such as, inquiry-based learning can lengthen the retention time of new knowledge, improve students' ability to solve problems and increase students' motivation for learning.

METHODOLOGY

A quasi-experimental friction learning experiment was designed in this study. A middle school teacher from the High School Affiliated to Renmin University of China in Beijing experimented with the system and evaluated the usability and acceptance of the system.

Material

The experimental materials for the experiment group include one wooden slope, a wooden sliding block and a mobile device for the AR system (as shown in Figure 1). The slope and sliding block act as real objects that generate friction. The AR experiment system was built with Unity 3D engine and installed on a mobile phone with an android operation system. The Vuforia Software Development Kit (SDK) library was selected as the tracking algorithm. As shown in Figure 1, distinct feature points have been chosen to identify and track the real objects.

![Figure 1. Experiment Environment](image)

Experimental Procedure

The system was established as a useful tool for middle school teachers to teach the concept of friction. A quasi-experimental friction learning lesson was set up to verify the usability and stability of the system. The experiment was conducted to help students generate explicit concept about static friction, dynamic friction and the element factors that influence the statement of friction.

The friction concept was experimented on the wooden slope. With the angle between the slope and ground changed, the strength and state of friction will change simultaneously. Therefore, the angle between the slope and ground should be calculated before the experiment. With the tracking algorithm of Vuforia SDK, the normal vector of the image target can be easily obtained. After acquiring the normal vector of slope \( \vec{n}_1 \) and normal vector of slope \( \vec{n}_2 \), the angle of the two planes can be calculated as:
The AR experiment system consists of two experimental scenes. In the first scene, the main purpose of designing this scene is to show the virtual visualisation of abstract force on the real sliding block through AR technology and let students have an intuitive sense of such forces as gravity force, supporting force, friction force as well as net force. When the sliding block is placed at the slope, the force analysis will be automatically visualised at the AR interface (as shown in Figure 2). Because the active force that is exerted by the students through AR technology can’t be obtained without such specific equipment as force sensor, when the student applies an active force, the visualisation of force will generate wrong results. If a user wants to exert active force on the object positioned on the oblique plane to test what factors will influence the state of friction, he/she can place some virtual objects on the slope to manipulate, which is the experiment content that we designed in the second scene.

![Figure 2. Force visualisation of real object](image)

In the second scene, students have 4 virtual objects to choose as experiment objects to be put on the oblique plane (as shown in Figure 3). The virtual objects include a box whose weight is 50kg, a puppy whose weight is 15kg, a sofa whose weight is 100kg and a cupboard whose weight is 150kg. The virtual friction coefficient between the virtual object and the real slope can be selected from 0 to 1. Additionally, user can apply virtual active force on the virtual object with a magnitude from -500N (downward along the slope) to 500N (upward along the slope). With such system settings, a student can easily design such inquiry-based experiments as:

1. Properties of static friction. In order to eliminate the influence of slope angle, the inclined plane should be put on the ground. A student can apply the active force on the object in one direction and increase the strength of the force slowly till the object starts to move, as well as observe the visualisation of the friction at the virtual object simultaneously. He/she can also change the direction and observe the experiment phenomenon. The student can easily draw the conclusion that the direction of static friction is opposite to the direction of motion tendency (direction of active force), as well as the strength of static friction and active force are equal.
2. Factors that influence the strength of kinetic friction. To conduct this experiment, control variable method should be taken as design principle. First, a student can put the slope on the ground. Then, normal pressure is chosen as constant variable. He/she can change the virtual friction coefficient, exert enough force on one specific object to make it move and read the magnitude of friction from the visualisation. Thirdly, friction coefficient is chosen as constant variable. The student can change the object and perform the same experiment. In the end, the student could draw a conclusion that the influence factors of kinetic friction strength are friction coefficient and normal pressure.

3. Dynamics of a virtual object when the active force’s magnitude is big enough to make the virtual object move. When the active force is big enough, the net force along the slope is greater than zero, so the state of the object is unstable and the object will speed up. The proposed system allows users to control the active force in real time, so that the object could be controlled to speed up or slow down and various interesting results could be obtained if the object is controlled properly. For instance, when the object is moving upward along the slope, if the active force is set to zero, the velocity of the object will slow down and finally become zero. The student can then observe that the direction of friction suddenly changes to the opposite direction at the zero-velocity moment.

![Image](image-url)

Figure 3. Force visualisation of virtual object
Though the experiments illustrated above are not very complicated friction experiments, they are attractive and impressive with educational attributes of visualisation and inquiry-based experiments for the beginners who don’t have explicit conception about fiction. To verify the usability of this system, we conducted an interview with the teacher about the research question of this paper: effectiveness, acceptance and satisfaction of this AR based friction experiment system.

RESULTS AND DISCUSSION

As noted above, the AR based friction experiment curriculum was motivated by two key design principles: abstract conception visualisation and inquiry-based experiment. Through the interview with the experienced middle school teacher, we obtained the following useful suggestions about the AR based friction experiment system.

First, the proposed AR based friction experiment system is more effective than the traditional ways. The visualisation of virtual force can effectively reduce cognitive load for beginners to learn the concept of friction. What’s more, the inquiry-based experiments can impress students and dramatically extend the retention of knowledge memory.

In addition, the proposed AR based friction experiment system could act as a useful teaching tool. The AR lessons provided opportunities for middle school students to learn integrated STEM contents and practical skills of friction experiment. Such learning experiences could be critical in nurturing students’ STEM interest and motivating them to take part in more science experiment activities.

However, there are also some shortcomings about the AR based friction experiment system. First of all, the stability of the experiment system needs to improve. The tracking method of the system is from Vuforia SDK library, which depends on image targets. When the image target is out of camera’s view, the virtual objects will become unstable. Besides that, students have to conduct the experiments one by one and can’t conduct the experiment through cooperation. So more interaction modes should be added on the experiment system.

CONCLUSION AND FUTURE WORK

We embedded AR into authentic inquiry activities so that students could experience when and how to carry out experiment to develop explicit concepts of friction by themselves. Having in mind that inquiry-based hands-on experiment can be helpful for knowledge construction, the visualisation feature of present AR application was conceived to improve students understanding and involvement in physics friction fundamental concepts, to contribute to increased STEM motivation by fostering their interest in the use of technologies. We found evidence that embedding AR in authentic inquiry to be more effective in developing student’s concepts of friction compared to the traditional methods, based on the viewpoint of the teacher.

AR lessons provide authentic inquiry activities with visualisation of abstract friction, so that the teacher gets satisfaction with the performance of the experiment system, as established in this paper. We do believe that this AR based friction experiment system can be used as a useful experiment mode. It is strongly suggested that more AR based STEM lessons applications be developed to motivate and engage students in transdisciplinary learning with new technology and authentic situations.
More evaluation experiments about the usability of this system should be conducted in the future, especially experiments with student participation. Only in this way can advantages and disadvantages of this system be fully discovered, and improvements realised.

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ABSTRACT

The main issue that this project addresses is testing a model of teacher professional learning and theorising about the aspects of the model that influence teacher beliefs and practices. The focus of this study was to determine if a year-long engagement in a sustained coaching model of professional development could change the beliefs and practices of teachers with respect to instruction and assessment in mathematics. A grounded theory methodology was used to support theorising about the effectiveness of a specific teacher professional development model. Data was collected from surveys (both pre- and post- the professional development sessions), interview data (both pre- and post- the professional development sessions), and researcher field notes. Ten middle school teachers and one consultant engaged in the year-long professional development. At the time this paper was submitted, the data collection was still in process. All data will be analysed by the time of the conference. Findings and conclusions will be presented then.

Keywords: Teacher professional development, mathematics, middle school

INTRODUCTION

Effective teacher professional development that contributes to a change in teacher beliefs and practice is a topic that has been garnering much attention (Knight, 2002; Loucks- Horsley & Matsumoto, 1999; Russo, 2004; Stronge, Ward, & Grant, 2011). Traditional models of one day professional development sessions with no follow-up have been shown to be ineffective in impacting teacher practice and that long-term support is needed for teachers to begin to change practice (Glazer & Hannafin, 2006). The model of professional development used in this project draws on the elements of effective professional development that have been articulated in the literature and has been implemented successfully with secondary mathematics teachers (Marynowski, 2013, 2014) as an effective way to influence teacher beliefs and practices. Further to this, the focus of the professional development should be on high yield teaching practices including formative assessment (Black & Wiliam, 1998).

The research question guiding this study is: Can year-long engagement in a sustained coaching model of professional development change the beliefs and practices of teachers with respect to instructional and assessment practices in mathematics? Additional questions are: What processes within the sustained coaching model supported or proved to be a barrier to teacher change? and What is the experience of teachers as they engage in the sustained coaching model of professional development?

The following sections outline relevant research pertaining to formative assessment and teacher professional learning and then details the research project. As this project is still in
the data collection phase (last data collection June, 2018) final conclusions and results will not be presented in this paper but will be presented at the conference.

LITERATURE REVIEW

Teachers guide the learning process in the classroom, and as a result, ultimately, they are responsible for raising learning standards in the classroom (Black & Wiliam, 1998). Recently, concerted attention has been paid to developing effective models of professional development for teachers that include an element of coaching (Beauchamp, Klassen, Parsons, Durksen, & Taylor, 2014; Russo, 2004). Historically, most professional development opportunities took the form of workshops or faculty meetings; however, these opportunities often do not promote significant changes in practice. For example, there is often a lack of follow up and ongoing support provided for teachers after these opportunities take place, which may hinder their ability to put what they have learned into practice (Kelleher, 2003). Consequently, noticeable improvements in the classroom may be lacking. Kelleher (2003) argues more resources should be put into providing professional development opportunities for teachers, professional learning should be implemented in the classroom daily (as this has shown to produce better student outcomes), and professional learning opportunities should be directly related to specific academic goals.

Additionally, in order to raise standards and student achievement, teachers typically require ongoing support and guidance to improve teaching methods. Wiliam (2007) argues formative assessment practices are the most cost-effective strategies for enhancing teacher performance and addressing individual student needs. Formative assessment has been described as adjusting teaching methods in order to fit the learning needs of each student (Wiliam, 2011), and it has been related to more in-depth learning, lifelong learning, and an improvement in academic success for students (Clark, 2012). Wiliam (2011) argues policies directed toward raising student achievement have failed in the past because they do not focus on improving teacher practice. One way to improve teacher practice is to train teachers in formative assessment strategies and techniques.

Characteristics of Effective Teacher Professional Development

Characteristics of effective professional development include being sustained over time, embedded in teacher practice, focused on a specific teaching practice, provided by an expert in the area, responsive to teacher needs, and include an element of follow-up or accountability (Marynowski, 2014). Each of the characteristics listed are in direct contrast to traditional forms of teacher professional development that exists as one-time workshops. Kennedy (2005) investigated and analysed existing models of continuing professional development and found they could be grouped into 9 categories: training, award-winning, deficit, cascade, standards-based, coaching/mentoring, community of practice, action-research, and transformative. Kennedy (2005) described elements of each of the models and identified strengths and weaknesses of each. The coaching/mentoring model emphasised training and support that can occur daily within the school by an expert, in addition to collaboration among colleagues where knowledge is to be shared as often as needed. This model, along with the community of practice model, showed the most connection to the classroom and evolution of teacher practice.

Additional research supports the use of a coaching model of professional development. Russo (2004) argued the use of on-site coaches can improve teacher practice. Coaches are typically experts in a particular area who work with the school by providing the teachers with support and guidance in order to help them develop and implement new teaching strategies often aimed at increasing student achievement (Russo, 2004). Coaches often work with small
groups of teachers or in a one-on-one setting. School based coaching is becoming more prominent, especially because other forms of professional development (such as workshops, conferences, or lectures) do not have favourable views due to their lack of ongoing consistency, the lack of ongoing support, and the lack of follow up (Rhodes & Beneicke, 2002; Russo, 2004). Additional research has emphasised professional development should occur in the everyday classroom, teachers should be provided ongoing guidance and support, the type of professional development should be tailored to the grade/subject the teacher is teaching, and teacher collaboration should be emphasised for mutual support and learning (Beauchamp et al., 2014; Russo, 2004). Furthermore, when school based coaching is utilised, teachers are often made accountable to learn and implement these new teaching strategies (Clement & Vandenberghe, 2001). Other areas of professional development, such as workshops, may be lacking this accountability (Russo, 2004).

Rhodes and Beneicke (2002) discussed the positive outcomes of coaching, mentoring, and peer-networking in enhancing teacher learning and professional development, which ultimately contributes to student learning. The benefits of these practices also include an increase in teacher collaboration, which can contribute to the empowerment of teachers, and an increase in teacher learning (Loucks-Horsley & Matsumoto, 1999).

**Teacher Professional Development with Respect to Formative Assessment**

Black and Wiliam (1998) brought forth the strength of formative assessment as a way to improve student learning. Since then, several studies have demonstrated that formative assessment indeed has an impact on student learning (e.g. Clark, 2012; James & Folorusno, 2012). Additionally, several studies have explored teacher professional development with respect to formative assessment (e.g. Marynowski, 2014; Marynowski, 2015; Wiliam, Lee, Harrison, & Black, 2004; Wiliam, 2007). Formative assessment in conjunction with topics that the teachers identified they wanted to engage in were the focus of the professional development within this project.

**RESEARCH DESIGN**

This research project draws on qualitative research methodologies to respond to the research question exploring teacher engagement in professional development. Constructivist grounded theory (Charmaz, 2006) framed the research processes and will be used to theorise about teacher professional development. Constructivist grounded theory allows for the articulation of a theory regarding a process that draws on participants’ experiences through engaging in the process under investigation. Timmermans and Tavory’s (2012) process of abductive analysis with respect to theorising within a constructivist grounded theory methodology, which allows for the development “generating novel theoretical insights” (p. 174), will be used as the basis of the analysis of the qualitative data. Bronfenbrenner’s bi-ecological model of human development (Bronfenbrenner, 1999; Bronfenbrenner & Morris, 2006; Marynowski, Mombourquette & Slomp, 2017) will be used to frame the aspects of one’s personal ecosystem that influence the degree of teacher change.

**Research Processes and Timelines**

The research project ran through the 2017-2018 school year in Alberta, Canada. Data sources included a pre- and post- survey of beliefs and practices in assessment, individual pre- and post- interviews, researcher notes throughout the sessions, observation notes from participants as we engaged in classroom observations, and artifacts produced as a result of the professional development activities that were engaged in. In this project, the researcher was also the coach. This project focused both on assessment and mathematics instruction and was
drawing on the skills and knowledge of the researcher to provide the professional development.

Participants

An invitation to participate in the research project and professional development series was sent to all teachers in a rural school division. 10 teachers and one consultant within the school division agreed to engage in the professional development with eight of those teachers and the consultant also agreeing to engage in the research components.

Of the eight teachers, three have more than 15 years teaching experience, three have between five and 15 years of teaching experience and two have less than five years of teaching experience. The consultant had 15 years of teaching experience and one year as a consultant. Each of the teachers was teaching mathematics to students in at least one of the grades 6 – 9. One teacher was teaching mathematics to a single grade while the rest were teaching multiple grades, often in the same class. The consultant’s role was one of an assessment coach for all teachers within the division. In addition, two of the teachers were trained as mathematics teachers, five of them were trained as science teachers, and one was trained as an art teacher. One of the participants was also the principal of the school that he was teaching at. All 11 participants engaged in all aspects of the professional development.

Timeline/Professional development activities

In September 2017, teachers were brought together, introduced to the project, and completed the first administration of an Assessment Survey. The Assessment Survey explores teacher beliefs and perception of practices with respect to assessment (Marynowski, Mombourquette & Slomp, 2017). Teachers were then individually observed teaching by the coach/researcher and were interviewed at that time.

The purpose of the observations was twofold: first to develop a rapport between the coach/researcher and the teacher; and second to have the teacher become comfortable with having observers in her classroom in preparation later observations by colleagues. The interviews focused on their beliefs about effective professional development and what the teachers hoped to learn from engaging in the professional development sessions.

The coach/researcher planned subsequent sessions based on what the teachers had offered during those interviews. Teachers were then brought together three additional times, once per month, and engaged in professional and academic reading, discussions around the readings, and activities that modeled the practices that were presenting in the readings.

In addition, at the conclusion of each large group session, teachers were asked to make a ‘commit to try’ to the rest of the group. In between sessions, each teacher committed to trying something new that they learned from the session in their classes. At the beginning of the next large group session, each teacher shared what they tried and how it worked.

After three large group sessions, teachers were then placed into groups of 3 or 4 and organised classroom observations of each other’s teaching. The coach/researcher designed an observation tool that focused on the assessment practices that were being engaged in and the engagement of students in doing mathematics. The purpose of the observation tool was to keep the observations neutral and to keep the observers focused on the topic of the observation. The coach/researcher also participated in each of the classroom observations.

Once the observations were completed, teachers were surveyed about the value of the activities they had engaged in so far and were asked what they preferred the next steps to be. Based on that feedback, the coach/researcher brought the teachers back for three large group
sessions, one per month, focused on assessment and pedagogical practice that, again, incorporated professional readings and discussions around the readings. At the final session, teachers completed the Assessment Survey again and were asked to sign up for follow up interviews. Final interviews were being conducted after this proposal was submitted.

RESULTS AND DISCUSSION

At this moment, without detailed analysis of all of the collected data, the results and discussion are anecdotal and descriptive in nature. Even though the full process of grounded theory has not been undertaken, emerging ideas have been identified.

Unanticipated Consequences

There were three unanticipated consequences of the professional development sessions and research project. The first is that the teachers in this group continued their engagement with each other and the ideas from the sessions throughout the rest of their professional development throughout the year. In this school division, several days throughout the year are assigned to teachers for them to engage in self-selected professional development where they can form their own groups and decide on their goals for their group. The teachers from this research project chose to continue working together to develop resources that embodied the ideas that they were learning from the readings and the professional development sessions.

The second unanticipated consequence is that several of the teachers took the ideas from the readings and professional development sessions and integrated them into other areas of their practice. For example, one of the participants was also teaching a robotics course and integrated multiple formative assessment strategies into that course as well as the mathematics courses. The participant who was a principal introduced some of the strategies to the staff at the school and many of the other teachers started to use them.

The third unanticipated consequence was that the consultant was learning not only assessment and teaching strategies but how to engage teachers in purposeful and effective professional development. The coach indicated that he would be using elements from the model that was implemented this year to inform his work in the school division over the course of his tenure as a consultant.

Regardless of the outcomes of the theorising of teacher professional learning and the change in teacher beliefs, the unanticipated consequences of the project provide support for the use of this coaching model as a way to influence teacher practice.

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AUGMENTED INTELLIGENCE AND THE FUTURE OF STEM ASSESSMENT DEVELOPMENT

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ABSTRACT

Automatic item generation is a rapidly evolving research area where cognitive theories, computer technologies, and psychometric practices are used to create models that produce test STEM items with the aid of computer technology. The presentation will focus on how STEM constructs can be captured in complex item models that can then be used to generate high quality, scenario-based STEM questions. The methods and processes described will help transform STEM item and passage/context development from what is currently a manual, labour intensive, non-scalable process to a specification driven, automated, highly-scalable process.

Keywords: Augmented Intelligence, automatic item generation, assessment development

1. INTRODUCTION

The principles and practices that guide the design and development of STEM educational tests are undergoing dramatic changes. One of the major catalysts for these changes arises from the application of technology to assessment best exemplified with the rapid development and application of computer-based testing (CBT) Drasgow, 2016; Drasgow, F., Luecht, R. M., & Bennett, 2006; Luecht, 2016; Sireci, S., & Zenisky, 2016).

Automatic item generation (AIG) is a rapidly evolving research area where cognitive theories, computer technologies, and psychometric practices are used to create models that produce test items with the aid of computer technology. It requires two general steps.

First, SMEs create item models that highlight the variables or elements in the assessment task that can be manipulated. An item model is similar to a template or mould that highlights the elements in the task that must be manipulated to produce new items. Second, the elements in the item model are varied using computer-based algorithms to generate new items. The purpose of this study is to describe the how STEM subject matter experts develop item models to generate complex scenario-based STEM question sets.

2. THE EMERGING TESTING TECHNOLOGY OF ITEM GENERATION

Item modeling provides the foundation for AIG (Bejar et al., 2003; LaDuca, Staples, Templeton, & Holzman, 1986). An item model is comparable to a template or mould that highlights the elements in an assessment task that must be manipulated to produce new items. Elements can be found in the stem and the options. The stem is the part of an item model that contains the context, content, and/or the question the student is required to answer. Options are the alternative answers that include one correct and one or more incorrect option. Scenario-based item sets as well as open-ended and technology enhanced items can also be generated using this methodology.
3. HOW ITEM GENERATION CAN PROMOTE ORGANISATIONAL INNOVATION

AIG could be interpreted as a shift away from the “art” of item development where assessment tasks are created solely from content expertise, experience, and judgment toward a new “science” of item development where these tasks are created algorithmically by systematically combining elements in the item model. Unfortunately, this characterisation is too simplistic. SMEs play a critical role in AIG. The SME is responsible for the creative task of identifying, organising, and evaluating the content needed to create test items. That is, the SME is essential in AIG for identifying the knowledge and skills required to think about and solve problems, designing meaningful item models, and specific the content for these models.

Computer technology also plays a key role in AIG. Computer technology is required for the generative task of systematically combining information in each item model. This algorithmic task is essential in AIG because large amounts of content specified by the SME must be combined to generate the items. AIG should therefore be considered a merger between the art and science of item development. The outcomes from the content-based creative task can be combined with the technology-based generative task to rapidly expanding the item development process. This new technology-based approach to item development is characterised by speed, efficiency, quality, and cost effectiveness.

3.1 Stage 1: Create Stems, Elements, and Options

The workflow begins with content expertise. The SMEs create the stems, elements, and options. The SME’s task is to identify the elements and then manipulate the content in the elements to create new items. The stems, elements, and options are created systematically using rules and rationales. The correct option requires implementing rules and rationales that yield the right answer. The incorrect options are based on rules and rationales that yield wrong, but plausible, answers.

3.2 Stage 2: Build Item Model in IGOR

IGOR is a JAVA-based program designed to assemble the content specified in an item model, subject to elements and constraints described by the SMEs (Gierl, Zhou, & Alves, 2008). Iterations are conducted in IGOR to assemble all possible combinations of elements and options, subject to the constraints. Constraints serve as restrictions that must be applied during the assembly task so that meaningful items are generated.

Stage 2 begins when information from the Stage 1 database extraction is read into IGOR. Then, the item model, along with all associate content in the model, is created and formatted in IGOR. An Item Model Editor window in IGOR permits the developer to structure each item model by manipulating content and adding the required constraints in the stems, elements, and options. Then, to generate items from a model, a Test Item Generator dialogue box in IGOR is presented where the developer specifies the item model file, the test bank output file, the answer key file, and the generation options.

3.3 Stage 3: Conduct Item and Model Quality Review

The SME is responsible for evaluating the content and the logic specified in the item model. This review is conducted by reviewing the generated item sample from Stage 2. It is also conducted by reviewing the AIG validation table (Gierl & Lai, 2016).

The validation table is a unique summary for SMEs that is only available with AIG. It is used in Stage 3 to evaluate the structure of the knowledge and skills required to produce the correct and incorrect options for the generated items. It also provides a way to describe and evaluate the target construct for the assessment. The validation table contains a summary of the concept required to produce the correct option. If the models are correctly specified,
then the generated items will reflect the correct combinations of content and logic outlined in models.

3.4 Stage 4: Add Themes and Expand Item Models

Stages 1 to 3 are implemented to create an accurate item model capable of generating high-quality test items. In Stage 4, the generative capacity of the item model is expanded dramatically in two ways (Gierl, Lai, Hogan, & Matovinovic, 2015).

The first type of expansion requires the addition of themes. These themes serve as additional content layers in each model so the names and contexts change in the generated items. The second type of expansion requires the elaboration of the item models so they measure different types of knowledge and skills. By identifying different types of knowledge and skills, different but related types of item models can be created.

In sum, Stage 4 is a model expansion step where the SMEs can use their results from Stages 1-3 to elaborate their item models to include different themes and to measure different curricular outcomes. These additions result in a significant increase in the generative capacity of the original Stage 1 item model.

3.5 Stage 5: Generate All Items and Export to Bank

In Stage 5, all of the items from a model or set of related models are generated. The format of the generated items is customised for each content area and grade level. Typically, the IMS Question and Test Interoperability specification (QTI) is used to define a standard format for the generated items. QTI permits a relatively easy exchange of content between authoring and delivery systems, repositories, and learning management systems. The generated items, saved in QTI format, are exported into the item bank for use on educational tests.

4. RESULTS

A summary of the outcomes from the 5-stage workflow is presented in Table 1. Using this workflow, one, 3-member, SME team created 10 different mathematics models that generated more than 68,907 items. The number of themes per model ranged from 2 to 5. The number of grade levels covered with a modified model ranged from 2 to 5.

The time to implement Stage 1 ranged from 1 hour to 1 day; for Stage 2 from 30 minutes to 2 hours; for Stage 3 from 15 minutes to 1 hour; for Stage 4 from 1 to 3 days; and for Stage 5 less than 1 hour. Hence, the total amount of time to implement all five stages in order to produce high-quality, content-specific items ranged from approximately 1 to 6 days per model.

In a recent 18-month development cycle, three, 3-member, SME teams created 54 models that resulted in the generation of more than 651,000 mathematics items across the elementary, junior high, and high school levels.

<table>
<thead>
<tr>
<th>Item Model</th>
<th>Themes</th>
<th>Grade Levels</th>
<th>Generated Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>3</td>
<td>&gt; 10,000*</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>660</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
<td>&gt; 10,000</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3,198</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>3</td>
<td>&gt;10,000</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>3</td>
<td>3,468</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>4</td>
<td>8,521</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>4</td>
<td>3,060</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>5</td>
<td>&gt;10,000</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>5</td>
<td>&gt;10,000</td>
</tr>
</tbody>
</table>

*Item generation was truncated at 10,000 as an upper bound.

5. CONCLUSIONS

AIG is a method that combines content expertise with technological innovation to solve the practical problem of rapidly expanding the item development process. AIG is a method for using models to generate items with the aid of computer technology. The purpose of our study was to describe how scenario-based mathematics items can be generated using AIG using a specification driven, automated, highly scalable process.

REFERENCES


Challenges of Implementing Design Thinking Process in the Primary Classroom

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Abstract

We present the preliminary findings of a one-year ICT Collaboration project, where design thinking was introduced to a primary school in an inner-city suburb of Brisbane, Australia. The project aim was to develop teacher skills in key areas of the Design Technologies curriculum. Six teachers were introduced to design thinking at one professional development day, following which the teachers were invited to apply these skills in their classrooms. The teachers were offered weekly support from the university team who visited the classroom when digital technologies were taught. The project was analysed from a qualitative perspective; data consists of interviews with the teachers, observations in the classroom. Findings show that design thinking challenges teachers in various ways. The creative and process-focused style of teaching resulted in the teachers adjusting the structure of their ordinary pedagogical approach. Ultimately, they found the design thinking processes could be adapted to diverse subject areas, and helped students with their metacognitive thinking.

Keywords: Design Thinking, Digital Technologies, Professional Development, Learning Process

Introduction

Beyond literacy and numeracy, children will need to acquire diverse skills in school to adequately prepare them for the (in some cases as-yet-unknown) careers and professions that will be in demand in the next decade. Design thinking and systems thinking are approaches that provide a framework to prepare children to help them manoeuvre through the increasing pace of change (Razzouk & Shute, 2012; Shute & Torres, 2012). These processes develop skills in problem solving, creative and critical thinking, collaboration and innovation, open-minded perspectives and analytical mind-sets.

In the past fifteen years, design thinking has migrated from design studios into other professional arenas as an approach to innovation. It was widely adopted in the business world as a way to address problems that needed new and innovative solutions and gain competitive advantage (Johansson-Sköldberg, Woodilla, & Çetinkaya, 2013). It has also become a mainstay in tertiary degrees outside of design schools, e.g. in business, ICT and management.

The development of design thinking as a packaged toolset has allowed participants from a broad range of backgrounds to enact processes that allow them to deconstruct complex problems and find alternative solutions that are creative, innovative and human-centered. Design thinking is now one of the main perspectives that underlies the Australian digital technologies curriculum, being seen to have the potential to train students in diverse and fluid thinking. Although the term “design thinking” is widely used in the curriculum, its implementation is still to be embraced by and evaluated in primary schools.
There is a distinct process orientation to the practice and pedagogy of design thinking that presents a number of challenges to its successful introduction in classrooms. Prior research has drawn attention to important dimensions including fostering a creative environment (Davies et al., 2014) facilitating productive collaboration (Brown, Collins, & Duguid, 1989), encouraging flexible and possibility-oriented mind-sets; and supporting students’ reflection on practice (Carroll et al., 2010).

Teaching the processes of design offers the potential for children to develop their own methods of deconstructing open-ended problem spaces (Looijenga, Klapwijk, & Vries, 2015). Giving students autonomy over their learning allows students to create more meaningful engagements and be intrinsically motivated in subject areas (Roth, 1998; Stefanou, Perencevich, DiCintio, & Turner, 2004). Allowing students to take responsibility of their own learning clearly does not mean leaving students without guidance or support; rather it means teachers need to adopt a different role in the classroom (Viilo, Seitamaa-Hakkarainen, & Hakkarainen, 2011).

This role is more in line with being a tutor, one that scaffolds students through a process to a viable solution, but in such a way that the student can reflect upon their own practices of developing ideas (Craft, 2010; Wood, Bruner, & Ross, 1976). Building on this work, the main challenge we address in this paper is the development of this pedagogy of process; how these approaches are enacted in the primary classroom, how teachers assimilate them into their existing teaching practices, how they adapt to evaluating process over outcome, and how researchers can support teachers in this transition.

PROJECT BACKGROUND

The ICT Collaboration project was a joint endeavor between a primary Catholic school in suburban Brisbane and The University of Queensland. The main purpose of the project was to build sustainable Digital Technologies in the school for all year levels. The three main aims of the project were to:

1. Develop teachers’ understanding of the new components of the Australian Curriculum: Digital Technologies, and in particular a foundation in computational, systems and design thinking.
2. Create opportunities for teachers and students to become familiar with various types of hardware and software to be purposefully integrated within the curriculum areas.
3. Create sustainable teaching and learning practices.

The initiative was to support teachers to develop skills in key areas of the digital technologies curriculum, and to provide the teaching staff with not only professional development (PD) courses but to also offer in-classroom support. In this article, we present the preliminary findings of a one year long project focusing on design thinking.

METHODOLOGY

Initially, teachers were invited to attend PD workshop on design thinking. The teachers consisted of one teacher from each year level (preparatory to year 6, excepting grade 3 teachers who were involved in another event) and one project leader from the school’s management team; in total six teachers and one project leader (see Table 1). The first workshop was designed to allow teachers time to run through a shortened and intense introduction to design thinking, where they were involved in activities facilitated by researchers who scaffolded them through a design process.
At the end of the session, teachers were asked to reflect on their experiences and to discuss how they might apply it to their own classrooms. Information and activity sheets were also provided, as a means to support teachers who wanted to adapt or implement some the methods covered in their own classrooms. These contained information on the different phases of design and strategies for implementation.

After the PD workshop, one supporting member of the research team visited the teachers’ classroom for one hour per week while the teachers delivered content to the classroom. The intention was for a support teacher to be on hand to offer help should it be needed, and to create the possibility for a co-teaching partnership to develop (Roth, Masciotra, & Boyd, 1999). Observations were made during this period and documented in hand-written notes by the lead researcher.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Grade Level</th>
<th>Teaching Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Prepatory</td>
<td>2 Years</td>
</tr>
<tr>
<td>T2</td>
<td>Grade 1</td>
<td>20 Years</td>
</tr>
<tr>
<td>T3</td>
<td>Grade 2</td>
<td>23 Years</td>
</tr>
<tr>
<td>T4</td>
<td>Grade 4</td>
<td>3 Years</td>
</tr>
<tr>
<td>T5</td>
<td>Grade 5</td>
<td>12 Years</td>
</tr>
<tr>
<td>T6</td>
<td>Grade 6</td>
<td>8 Years</td>
</tr>
</tbody>
</table>

Collected data comprised of observations and audio recordings. Observations were taken while operating as in-class support. Focus group interviews were conducted at the conclusion of each term and again at the end of the year. The interviews were semi-structured, to allow for greater teacher input and direction. Interviewees were split up depending on grade levels - upper level 4 - 6 and lower level Preparatory - 2. (Grade 3 is not represented as they had not participated in the PD days). Table 1 shows an overview of the teachers, their experience and what grade levels they teach.

From the collected audio recordings and observations, we categorised the teachers’ responses and practices into themes relevant to the aims of the project. These are introduced and discussed below.

**RESULTS AND DISCUSSION**

The pre-interview discussions revealed that design thinking was not an area that teachers knew much about. Two junior teachers (T1 and T4), who had been teaching for less than three years, expressed disappointment that they had only limited amount of practical experience teaching digital technologies. T4 pointed out “I thought I knew what it was, but wouldn't have known how to roll it out”. This highlights the importance of providing not only PDs for teachers to develop greater exposure to challenges introduced by the curriculum, but meaningful opportunities for teachers to learn while they are teaching (Roth, 1998).

Each interview was analysed to identify episodes from the teachers’ experiences that helped us identify issues, challenges and opportunities for successfully implementing design
thinking into the primary curriculum. The overarching themes that we identified were assimilation, implementation and assessment:

**Assimilation** - the way in which teachers made sense of the theory, assimilating the new process into the classroom.

**Implementation** - the way teachers perceived how students were engaged throughout the learning process.

**Assessment** - how teachers made adjustments, changing their focus from the end of term product to evaluate students’ engagement with the process.

**Assimilation of theory into practice**

After the initial PD training and reflection sessions, researchers had the expectation that teachers would use (but adapt) what they learnt in the PD to a more relevant content area. One of the teachers (T1) told us they had gone back to their class and then tried the design thinking process with their students and found it quite intense. When asked for more details on how they had worked with the material, it became apparent that the teacher had lifted out the methods from the PD training and reduced the time for the activities to fit into a one hour session.

This was in contrast to how the concept of the process had been introduced in the PD, where participants were encouraged to allow time for reflection and development of ideas. In the interview, we specifically asked the teachers about the phenomena of the ‘lift and drop’ application of PDs. Teachers described how they had used the process exactly as the PD, as a way for them to discern how it would work in the classroom, and as a way for them to understand and reflect on how they could adapt the activities to suit their students’ needs. From our observations, we had noted T4 had used a design thinking process three times. Each time, they expanded and applied the process to other curriculum areas.

The final project of the year consisted of developing new technology that would allow Australia’s ‘first fleet’ to be able to contact each other between ships on their voyage. T4 described that one of the major benefits of applying the process to different areas was students started to develop their metacognitive skills and reflecting how they think about thinking: “...[a] benefit [for] them: the more they experience the process I think, the less they think about the process and the more they think about their own thinking and designing” (T4)

Most of the teachers recounted how they had used parts of the design thinking processes in other subject areas, “It hasn’t been like an extra thing, that that was something that I was really worried about, oh no I have to timetable extra stuff in, Umm but we but I was definitely be able to do a lot with geography umm mapping and even doing maths with shapes and things like that” (T4). While teachers initially ‘lifted’ the process fairly straight from their initial experience of it in the PD, those that worked with it iteratively in the classroom found that the application to diverse curriculum areas, and that students also benefited from repeated exposure to the process, with respect to the development of their thinking strategies.

**Implementation**

Several insights emerged from discussions and observations on how the teachers decided to implement design thinking into their classrooms.

Throughout the process, teachers were encouraged to work with the students collaboratively. Allowing students to work on open-ended problems as a collective and
together in smaller groups meant that students wouldn’t always be reliant on the teachers to provide solutions.

In the upper year levels, teachers discussed how they needed ways of nurturing students into being productive members of group work. They needed to develop strategies such as teaching students to teach others and break down tasks so that workload was shared between students. “To some extent that’s because it is a different type of learning, ...It is different type of pedagogy and as you were saying to maths and most other learning areas, because it’s sort of based around a group dynamic, in a lot of cases, so there lots of great opportunities for peer tutoring and peer learning. So I for one was sort of encouraging them, to sort of say in your group you need to share your skills which is obviously challenging part of it but a very valuable part of it” (T5).

In such cases the teacher had to become a different kind of actor in the classroom, one that scaffolded the work rather than being a master of it. “...It’s a really different model from the traditional student-teacher relationship. I think the role of the teacher changes and becomes similar to to a sort of peer and tutor and you’re sort of going around and seeing how do we solve this problem together see if we can work it out and see how we go... it’s not instructional....” (T5). This was not always viewed positively by the teachers, as some felt overwhelmed with trying to learn the content themselves and could not immediately see how it was making a difference to student outcomes.

In the younger years, teachers also discussed how they and students had to learn to work in collaborative environments. What surprised them the most was those types of student who showed resilience and creativity, were not always the high achievers in other subject areas. “The children that I expected to take it and do well and fly with it, didn’t necessarily, they were the ones breaking down into tears, couldn’t cope when it didn’t work and had problems when they had to problem-solve” (T3).

Those students who usually did well with instructional type learning, became disoriented with the open-endedness of the problems. When pressed to reflect on what it was about design thinking that initially made the usual higher achieving students hesitant, teachers responded with two main areas. The first related to the school’s focus on achievement; “I think in the classroom we become very fixated on achievement and academics, and this wasn’t ... necessarily academic, this was who could be the most creative” (T3). The second was that some students have difficulties when there is no clear right and wrong answer; these students tended to struggle.

Further research is needed to ascertain if this is a phenomenon associated with the initial reaction to these novel activities in the classroom, and if further implementation of these approaches will generate similar results. T4 discussed briefly how they began to see a shift in students thinking from “I can’t” mind-set to an “I can”, and how this understanding was a motivator for some children. “The second or third time round now, he’s so not much about can and can’t do this ... [but now] is sort of (clicks fingers)... go”.

Most teachers agreed that the initial implementation has allowed a different type of learner to flourish—one more comfortable with peer engagement, open-endedness and exploring possibilities rather than achievement and certainty.

**Assessment**

In the curriculum, the assessment for Digital Technologies is quite broad, and open to interpretation. A probing area for our research was to see how well teachers coped with the divergent possibilities of design tasks. Teachers did express how broad it was, but in some ways also found that aspect was helpful in that they could still assess the process. Teachers
found a variety of methods for assessing the process, including interviewing students about how they had progressed and what they learned throughout the experience. Other teachers took notes as to what students were doing throughout the process. Teachers expressed that having a process to assess, enabled them to focus more on how well students listened to advice/feedback, iterated on and modified their ideas. Some students “struggle to modify their design, because they didn’t want to admit they needed anything to be fixed” (T2). This was seen as a problem, especially for encouraging creativity and giving students license to explore. Nevertheless, the focus on how students’ work (and collaborative work) rather than achieving predefined outcomes gave teachers opportunities to rework some of their own practices around assessment, and what constituted evidence of student learning.

CONCLUSION

Teachers are juggling the dual state of being both learner and teacher, when participating in PD training. Having PDs that provide materials for teachers to ‘lift and drop’ became a catalyst of the learning process that started at the initial PD day. The model of having the support staff on site to help when teaching design thinking processes was valued by the teachers, and helped them tackle unfamiliar aspects of the curriculum.

Design thinking is a process that can suit the modern classroom, scaffolding open-ended problem solving. Our research suggests that design thinking helped teachers encourage inquiry-based learning among their students, promoting reflective thinking and communication, even (and in spite of) teachers’ unfamiliarity with the concepts and practices of design thinking. Clearly, however, teachers need to be partners in any changes that are introduced to the culture of the classroom.

The more that teachers interact with design thinking or digital technology experts in developing these competencies, the greater success they are likely to have at developing and tailoring their practices. This was certainly the case in our preliminary study. Other researchers have found that teachers who take steps to develop their own personal entrepreneurship (Drent & Meelissen, 2008) tend to be more innovative in their implementation of technology.

Further research is needed on how best to support teachers in implementing design thinking in primary classrooms, and how to encourage them to shift traditional pedagogies towards a more student-driven, inquiry-based learning model. However, the combination of design thinking and digital technologies may necessitate a broader range (and flexibility) of assessment methods, particularly when the process is acknowledged as of equal importance as the final outcome.

REFERENCES


ABSTRACT

STEM (Science, Technology, Engineering, and Mathematics) initiatives and project-based learning are of current interest in both school and outside school contexts in Canada. However, an important question is whether or not current educational practices are sufficient in preparing students for the world they are to live and work in. This question prompts discussions about STEAM (Science, Technology, Engineering, Arts and Mathematics), a considerably new concept that is shifting educational paradigms towards art integration in STEM subjects. This research study will address the following major questions: What curriculum and instruction models of STEAM education are implemented in non-profit and in school contexts? How do classroom teachers view such models of STEAM education in meeting their curriculum and instruction goals? This study investigates the STEAM movement in Canada to better understand the STEAM instructional programs offered by non-profit organisations and by publicly-funded schools. I took a small sample of four different STEAM programs in Ontario, Canada, specifically the STEAM programs in two non-profit organisations and two in-school research sites. I carried out a qualitative case study. I conducted interviews, observations and data analysis of curriculum documents. There were a total of 108 participants, 24 adults (director and instructors/teachers) and 84 students. This paper presents preliminary research results of the descriptive data of the models of STEAM education researched and the observation data. These preliminary findings have implications for designing, implementing and researching STEAM programs.

Keywords: STEAM, STEM and arts, STEM and creativity, Art integration, Integrated curriculum, Art-based curriculum, STEAM and Canada.

INTRODUCTION

STEM (Science, Technology, Engineering, and Mathematics) initiatives and project-based learning are of current interest in Canada. However, an important question is whether or not current educational practices are sufficient in preparing students for the 21st century. This question prompts discussions about STEAM (Science, Technology, Engineering, Arts and Mathematics), which is shifting educational paradigms towards integrating the Arts in STEM subjects to address students’ lack of success in STEM subjects and their ability to make meaningful connections.

Educators have approached STEAM education in different ways, depending on available resources, developing STEAM schools, afterschool programs, clubs, out of school programs, non-profit organisations and/or community partnerships. This study investigates
curriculum and instructional models of STEAM education and how classroom teachers view these models in a Canadian context.

This research study addresses the following major question:

1. What curriculum and instruction models of STEAM education are implemented in non-profit and in-school contexts?

Several studies inform this research including literature on STEM/STEAM education, studies on art integration, school-based and higher education models, and STEAM education in Canada.

LITERATURE REVIEW

According to the Council of Canadian Academies (2015, p. xvii), “STEM skills are necessary . . . but they are not sufficient on their own . . . Other skills such as leadership, creativity, adaptability, and entrepreneurial ability may be required to maximise the impact of STEM skills”. Further, the integration of the arts provides students with multiple representations, multiple ways to approach a problem, multiple ways to express themselves, and multiple entry points of engagement that can bridge the achievement gap (Robinson, 2013).

School-Based Models

There are many schools that integrate the arts with STEM at the elementary and secondary level. For example, the Boston Arts Academy (BAA) is a STEAM school, in which “students explore the connections between the arts, science, and math, and incorporate new technology into their projects” (STEAM lab, 2016, para 1).

Another example is Union Point STEAM Academy (UPSA) (Ghanbari, 2015). UPSA “incorporates project-based learning through [the] lens of constructionism with a focus on authentic, experiential learning and meaningful design products” (Mote, Strelecki & Johnson, 2014, p. 2). The UPSA art integrated curriculum is child-centred and provides “access and equality for traditionally underrepresented students (low-income, female, and students of colour)” (Mote et al., 2014, p. 3).

Higher Education Models

Industry leaders are calling for, as well as rallying behind, the STEM/STEAM movement with the objective of supporting students to create, innovate, collaborate, and “approach problems both divergently and convergently” (Madden et al., 2013, p. 543). In response to this call, certain colleges and universities are beginning to integrate the arts with STEM disciplines at the post-secondary level through multidisciplinary programs and integrated courses.

STEAM Education in Canada

Canada has also taken an invested interest in STEAM and its potential benefits. Elizabeth Buckley School, located in Victoria, BC, is the first STEAM school in Canada (Elizabeth Buckley School, 2016). Additionally, several school boards in Ontario have created makerspaces that facilitate STEM/STEAM initiatives (Mulcaster, 2017). There are also several non-profit organisations in Ontario, such as STEAM labs and centres.

Researchers and units at universities also partner with school boards. Gadanidis, for example, incorporates song, visual arts and math stories in students’ activities which “add[s] excitement to children’s math learning” (Gadanidis, 2014, p.39). The activities developed by Gadanidis are low floor, wide wall and high ceiling activities that can allow students multiple entry points and multiple ways to approach a problem (Gadanidis & Hughes, 2011).
Theoretical Framework

I have adopted Papert’s constructionism and design-based learning theoretical frameworks. According to Papert and Harel (1991, p. 6) the most basic definition of constructionism is “learning-by-making”. Constructionism student-centred as students learn through discovery, exploration, building and making a tangible object (Alesandrini & Larson, 2002).

Design-Based Learning incorporates “hands-on problem solving, project-based learning and portfolio assessment” creating a “bridge between fine arts and other areas of the curriculum, such as science, mathematics, social studies, and language arts” through design (Davis, 1998, p. 1).

RESEARCH DESIGN

I carried out a qualitative case study (Yin, 2004). In order to triangulate the data, I used multiple sources, including a document analysis, observations and interviews. To respond to the questions on the kind of curriculum and instruction models of STEAM education implemented in non-profit and in-school contexts, I interviewed and observed the participants.

Methods of Gathering the Data

I took a sample of four different STEAM programs in Ontario, Canada. Specifically the STEAM programs in two non-profit organisations and two in-school research sites with a total of 108 participants, 24 adults and 84 students.

Interview data:

I interviewed a total of 52 participants. I conducted a conversational interview with the director, instructors/teachers and students of two non-profit STEAM programs and two school-based STEAM programs, using open-ended questions (Arthur, Waring, Coe, & Hedges, 2012).

Observations data:

To observe different curricular and instructional models, I also conducted several observations of instructors/teachers, students during STEAM lessons and I studied the learning environment at each research site and what happened naturally in this environment.

Document analysis:

I also carried out document analysis. The document analysis focused on the presence of STEM curriculum standards that are embedded into the lessons and curriculum documents.

RESULTS

This paper presents preliminary research results of the observation data. In this section I provide descriptive data of the models of STEAM education researched.

Non-Profit case studies: Both non-profit cases catered to ages 6 to 12 students and provided programs for teens/adults, were in urban settings, operated a co-ed model of teaching boys and girls together, used hands-on activities, cooperative learning, and the teacher’s role was taken as that of the facilitator. However, there were some differences as described below. Table 1 provides more details:

- **Case study 1**: Non-Profit 1’s physical learning environment is set up for small group work, with desks and chairs as well as floor mats and in a large space that is divided by movable walls as shown in Fig. 1. The pedagogy appeared designed to support
the process of making versus completing a project. As well, the teaching style appeared to be play/discovery learning in which the students construct their own knowledge. A case in point is students learning by physically touching and seeing how the motors of a remote control car work.

Figure 1. The physical learning environment of the Non-Profit 1 STEAM Centre.

Case study 2: Non-Profit 2’s learning environment was set as a computer laboratory for students to work individually or in pairs at desks. The pedagogy was designed to support students to individually design and construct STEAM products by the end of the course.

This STEAM centre supported the framework of hands-on discovery, inquiry-based learning and design-thinking. A case in point was when students were given the opportunity to create 3-dimensional shapes using modeling clay they then used that knowledge to create a 3-D image in Tinkercad to make a 3-D pencil topper as shown in Fig. 2.

Figure 2. Designs for 3-D pencil topper in Tinkercad by students at Non-Profit 2.
### Table 1. Type of Instruction/Pedagogy in Case study 1 and 2

**Observation: Classroom/Workshop Activities**

<table>
<thead>
<tr>
<th>Instruction/Pedagogy</th>
<th>Non-Profit Case 1</th>
<th>Non-Profit Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The instructor used:</strong></td>
<td>Not seen</td>
<td>Mini-lesson at the beginning of class with a presentation on a screen.</td>
</tr>
<tr>
<td><strong>Class Discussion</strong></td>
<td>Facilitated discussion, such as to discover how robots work, share what they created, and give other students feedback (e.g., to fix problem or create a better design).</td>
<td>Asked students: - brainstorming questions - to share their ideas in the whole group - to explain how to fix or debug their code</td>
</tr>
<tr>
<td><strong>Small group work</strong></td>
<td>Students worked at the table or on foam mats in groups of 2-3, when learning a new skill or technology.</td>
<td>Not Seen</td>
</tr>
<tr>
<td><strong>Learning Centers/Stations</strong></td>
<td>All stations (e.g., the Glue station, cutting station and the craft station) were in one room.</td>
<td>Stations (e.g., the computer room, the Laser/Wood cutter room, and the 3-D printing room) were located in multiple rooms on different floors.</td>
</tr>
<tr>
<td><strong>Teacher-Student Interaction. The lessons were design/inquiry based learning, and:</strong></td>
<td>Teacher-student interactions were extremely positive. Student-driven/centered. For example, students were guided through four stages of Maker Education Model: (1) Play, (2) Design, (3) Make, (4) Celebrate.</td>
<td>Teacher-student interactions were extremely positive. Both teacher and student driven. As student became more familiar with new software they were given more opportunities to explore and discover. The main pedagogy used was hands-on learning, inquiry-based and design thinking.</td>
</tr>
<tr>
<td><strong>Project-Based learning. Student designed:</strong></td>
<td>-hands-on activities all the time including the interactive class discussions in which students played with the technology.</td>
<td>- hands-on activities much of the time, such as modeling 3-D figures from clay.</td>
</tr>
<tr>
<td><strong>Hands-on activity. Student work involved:</strong></td>
<td>-own projects and were given freedom to select and use the materials available.</td>
<td>-own projects within the given parameters of the activity.</td>
</tr>
<tr>
<td><strong>Cooperative Learning. During the class:</strong></td>
<td>-on the foam mat or desks, students work together to solve a problem or to plan a design.</td>
<td>-students learned from one another. Students were given group challenges (e.g., the marshmallow build challenge to build the tallest free standing structure).</td>
</tr>
<tr>
<td><strong>Differentiation To facilitate different abilities</strong></td>
<td>The instructor used: - multiple ways to approach a problem, low floor, wide wall and high ceiling approach to learning and used flexible lesson plans.</td>
<td>-valued both the process and the product. Each student had a final product at the end of the course. -is flexible and allows students the flexibility to modify a task or use a different method.</td>
</tr>
<tr>
<td><strong>Teacher values, The instructor:</strong></td>
<td>- was not as concerned with the product, but more with the process. Students may not finish the project within the scope of the course. The process was completely dependent upon the individual.</td>
<td></td>
</tr>
<tr>
<td><strong>Assessment and documentation</strong></td>
<td>Utilised a website that featured the different programs offered and highlighted the student learning environment of the case through photographs and videos.</td>
<td></td>
</tr>
<tr>
<td><strong>Students demonstrated</strong></td>
<td>-high levels of engagement and positive attitudes towards STEM or STEAM</td>
<td></td>
</tr>
</tbody>
</table>
the following:
- self-motivation, self-regulation, self-confidence, curiosity, collaboration, communication, perseverance, innovation, critical thinking and problem solving skills

**School case studies:** Both in-school cases served students ages K-8, were in urban settings, used inquiry based models and had similar teaching styles with lessons aligned with the Ontario curriculum. However, there were some differences as described below. Table 2 provides more details:

*Case study 3:* In-School 1’s physical learning environment, a Makerspace situated in the library (Learning Commons), was similar to a STEAM center with work benches and stations on which students can make or build. The main pedagogy of the In-School 1 case was the inquiry model: Ask, Collect Ideas, Plan and Make. For example, the Grade 5 students asked the question, how can we get our robot to see? In their groups they collected ideas by researching online and reading books. They planned their designs by drawing a blueprint and listing the materials. Finally they used coding to program the robot to travel outside the perimeter of an irregular 2-D geometric shape, as seen in Fig. 3.

*Case Study 4:* In-School 2’s physical learning environment, the Makerspace, had both stationary and mobile stations. The main pedagogy of the In-School 2 case was the Design Inquiry Model. The grade 5 students used the Design Inquiry Process to create a product that entertained a target audience or served a function or purpose in their lives. Some students chose to build a pop bottle rocket for this project, as seen in Fig. 4.
### Table 2. Type of Instruction/Pedagogy in Case Study 3 and 4

**Observation: Classroom/Workshop Activities**

<table>
<thead>
<tr>
<th>Instruction/Pedagogy</th>
<th>In-School 1</th>
<th>In-School 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>The instructor used:</td>
<td>Mini lesson at the beginning of class with a PowerPoint presentation.</td>
<td></td>
</tr>
<tr>
<td>Small group work</td>
<td>Students talked in groups or with their partners at a centre.</td>
<td></td>
</tr>
<tr>
<td>A space in the Library, Library Learning commons had:</td>
<td>-A wall dividing the Makerspace and the library section.</td>
<td>-Movable centres so it can facilitate both the classroom activities and the clubs.</td>
</tr>
<tr>
<td>Makerspace Learning Centres /Stations:</td>
<td>-Work benches, a 3-D printer, scroll and band saws, sewing machine, Green Screen, LittleBits, E-textiles and Chibitronics bins. The library section had large collaborative tables, a carpet area and a computer lab.</td>
<td>-Collaborative tables, a mobile computer lab, Soldering and sewing, a Wood shop in the lower level, a Craft/loose parts bin, a Paper circuits bin, Squishy circuits, Remodeling computers and Green screen/stop motion centre.</td>
</tr>
<tr>
<td>Programmable software and technology:</td>
<td>-Several including micro-controllers, a 3D printer, sewing machine Green screen, programmable robots and other technologies.</td>
<td></td>
</tr>
<tr>
<td>Teacher-Student Interaction</td>
<td>Teacher-student interactions were extremely positive. A balanced model: model, shared experience, guided and then independent activities.</td>
<td>Teacher-student interactions were extremely positive. A partnering model: the teacher learned alongside students. The teacher was not the expert, but a facilitator and collaborator.</td>
</tr>
<tr>
<td>Centres were student-driven because students choose their level and centre. Inquiry Model: Ask, Collect Ideas, Plan (Design) and Make.</td>
<td></td>
<td>Student-centred and -driven based on a student’s individual needs. Students were able to choose their own level and explore their own ideas. Also used the Design Inquiry model.</td>
</tr>
<tr>
<td>Problem-Based learning</td>
<td>Students are given a challenge that they have to complete through programming or designing a model.</td>
<td>Not seen</td>
</tr>
<tr>
<td>Project-Based learning. Student design:</td>
<td>-own projects within the given parameters of the activity and the materials available</td>
<td></td>
</tr>
<tr>
<td>Hands-on activity</td>
<td>Lots of hands-on activities during the building/making stage.</td>
<td></td>
</tr>
<tr>
<td>Students had many hands-on activities, whether they were programming a robot, making a physical object or creating a pattern in Minecraft.</td>
<td>Many of the activities provide students with the opportunity to tinker/explore a new technology or skill.</td>
<td></td>
</tr>
<tr>
<td>Cooperative Learning</td>
<td>Students worked in groups or pairs to solve a problem.</td>
<td>Students worked in partners. The teacher encouraged students to consult with a student expert first before asking the teacher.</td>
</tr>
<tr>
<td>Differentiation To facilitate different abilities</td>
<td>Multiple ways to approach a problem, low floor, wide wall and high ceiling (simple to complex) approach to learning, open-ended problems with multiple outcomes and flexible lesson plans.</td>
<td></td>
</tr>
<tr>
<td>Teacher values: The product is</td>
<td>-both the process and the product.</td>
<td>-it helped the teacher assess what the student has learned from the</td>
</tr>
</tbody>
</table>
important because:  
Students were encouraged to keep building and making in a club or during the summer break.

### Assessment and documentation

The teachers documented the process through anecdotal notes. The two in-school teacher-librarians created a website with their personal observations, blog posts, and social media stories (photographs and videos).

### Students demonstrated the following:

- High levels of engagement and positive attitudes towards STEM or STEAM activities
- Self-motivation, self-regulation, self-confidence, curiosity, collaboration, communication, perseverance, innovation, critical thinking and problem solving skills

At each research site the students had high levels of engagement and positive attitudes towards STEM or STEAM activities (see Tables 1 and 2). During most of my observations students showed or demonstrated the following: self-motivation, self-regulation, self-confidence, curiosity, collaboration, communication, perseverance, innovation, critical thinking and problem solving skills (as shown in Tables 1 and 2). I also noticed that when the activities used familiar technology students did not show perseverance, innovation, critical thinking and problem solving skills (i.e. Grade 1 Activity hour of code). It was also evident that all the teacher-student interactions were extremely positive in each of the STEAM programs (see Tables 1 and 2).

### DISCUSSION

The findings of this study inform us that some features were common and some were different among both non-school and school contexts. In both non-school and school contexts, teachers/instructors differentiated instruction by using low floor and high ceiling activities, flexible lesson plans and providing multiple ways to approach a problem. Also, the teachers/instructors encouraged students to work collaboratively, problem solve, engage in hands-on activities, and design and create individual projects.

Both non-profit and in-school cases used some sort of inquiry-based model in their STEAM program, so students were given the opportunity to problem solve and use critical thinking skills to approach a problem that has multiple solutions (Ghanbari, 2015). All STEAM programs in this study reflected the constructionism tenet of “learning-by-making” (Papert & Harel, 1991, p. 6), and design based learning, in which students design a prototype or project to build. All of the STEAM programs had high levels of student engagement, positive teacher-student interactions and students had positive attitudes towards STEM or STEAM activities.

One new finding is thinking about assessment and documentation in a new light, in particular how educators at both types of sites assessed students when they were designing and creating STEAM products. The educators shared records of the learning and instruction that happened in the STEAM program with the community through documentation on a website, and thus were extending the “learning experiences to wider audiences and” contributed “to the collective knowledge about how students learn” (Krechevsky, Rivard & Burton, 2010; Mulcaster, 2017) in the STEAM settings.

### CONCLUSION

The STEAM instructional programs in this study offered by non-profit organisations and publicly-funded schools showed many similarities and differences depending upon the
learning environment, instructors, students and the available resources. These preliminary findings have implications for designing, implementing and researching STEAM programs. The results of this study promise to inform the practices of teachers who seek to engage and motivate students to learn STEM subjects by integrating the Arts.

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PERCEPTIONS AND PRACTICES OF MATHEMATICS TEACHERS' DE-PRIVATISED PRACTICES

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ABSTRACT

Considering the lower achievements of Mathematics in Fiji, this study has tried to provide a mechanism to promote de-privatisation of Mathematics teachers’ classrooms. However, before doing so, it was essential to determine Mathematics teachers’ perceptions of de-privatisation and evidence the current practices that were in place. Employing a mixed approach, data were gathered from six secondary schools using on-line questionnaire and semi-structured interviews. A total of 43 questionnaires and 9 interviews were analysed using quantitative and qualitative methods respectively. The major findings to emerge from the teachers were: 1) de-privatised practices in schools help improve teachers’ instructional practice; 2) close colleagues and the heads of department play a vital role in teacher improvement; 3) the major challenge teachers face in regard to de-privatisation of classrooms are the school culture and the workload; 4) school administrators play a vital role in promotion of de-privatised practices. Overall, the analysis of data has established that Mathematics teachers mostly are hesitant to engage in the de-privatised practices, hence there is a need to promote de-privatisation in Mathematics classrooms.

Keywords: Professional learning community, Mathematics teachers, developing nation, de-privatised practices.

INTRODUCTION

In Fiji, all children have access to education, but the quality varies depending upon if the school is located in a rural or urban area (Lingam & Lingam, 2013). English is mandatory and Mathematics is undertaken by almost all students. In 2015 approximately 97% of students did Mathematics in higher secondary (Ministry of Education [MoE], 2015).

According to Reddy (2017) the percentage pass in secondary school Mathematics exams at all levels have been below 50% (as cited in Singh, 2017). Hence, the Ministry of Education continues to take initiative to ensure that the quality of education in Fiji continues to improve (MoE, 2014). Some of the initiative include provision of free text books, localising the context, reviewing the curriculum through the formulation of the Fiji National Curriculum Framework (MoE, 2014).

Camburn and Han (2015) argued that practically every country in the world had carried out some form of curriculum reform over the preceding two decades, yet there is, time and again, inadequate support provided for the teachers to modify and advance new approaches to their teaching. It is important for teachers to undergo relevant professional learning to bring continuous development into their knowledge and skills.

School-based teacher learning with colleagues is becoming the leading form of professional learning, rather than teachers attending one-off professional learning activities (Darling-Hammond & Richardson, 2009). A number of international studies (DuFour &
Eaker 1998; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006) have discovered the benefits of teachers’ professional learning community (PLC), but this has largely focused on developed countries. There has been little research undertaken in developing countries like Fiji. Considering the lower achievements of Mathematics in Fiji, this study has tried to provide a mechanism to promote PLC through de-privatising Mathematics teachers’ classrooms. However, before doing so, it was essential to determine Mathematics teachers’ perceptions of de-privatisation and evidence the current practices that were in place. Furthermore, by identifying the enablers and the challenges, one could distinguish measures for sustainability.

LITERATURE REVIEW

Professional Learning Communities

A PLC consists of a group of people who take an active, reflective, collaborative, learning-oriented and growth-promoting approach toward both the mysteries and the problems of teaching and learning (Mitchell & Sackney, 2009). Creating effective PLCs requires professionals to assume responsibility beyond their own classrooms (DuFour & Eaker, 1998). In the school, teachers must be willing to share information and practices with others while focusing on results (Seashore, Louis, Wahlstrom, & Anderson, 2010) as the knowledge of teachers is extended when shared with colleagues. This practice of collaboration and sharing of ideas will promote a common goal and shared mission among teachers in a school, resulting in a culture open to sharing and to greater teacher and student learning (Seashore et al., 2010).

The literature has widely recognised the multi-dimensionality of teachers’ PLCs (Stoll et al., 2006) which includes organisational, personal, and interpersonal characteristics. Very few studies have taken separate characteristics into account while studying the potential facilitating factors. Vanblaere and Devos, (2016) argued that breaking down this concept into clear and distinguishable characteristics would increase the benefits of studies as these could then provide information on how specific features could enhance effectiveness. They also established that de-privatised practice was one of the core-interpersonal characteristics of teachers’ PLC.

De-privatised Practices

Vanblaere and Devos (2016) argued that it is important for schools to engage in professional learning methods that require teachers to de-privatise their classrooms; that is open classroom management, pedagogical approaches and teaching practices to their teacher colleagues through formal and informal invitations to them. This is an essential move since, for the last century, classrooms have been the domain of the individual teacher (Hiebert,Gallimore & Stigler, 2002; Stigler & Hiebert, 2009) which had deprived them of collegial learning. If this cultural change is achieved, Stigler and Hiebert (2009) argued that it will be characterised by embedded and stable teaching practices, which could improve teacher quality and, ultimately, student learning. Embedded learning involves sharing personal practice through engaging in peer coaching, lesson study, classroom observations and discussions (Stoll et al., 2006).

There is a significant amount of literature that supports the observation of both experienced and novice teachers as a valuable practice for teachers’ professional growth (Mohan, 2016). Another way to de-privatise classrooms to facilitate teachers’ professional growth is through team teaching (Jang, 2006). Team teaching involves a group of teachers working purposefully, regularly, and cooperatively to help a group of students learn (Sundarsingh, 2015). As a team, the teachers work together in setting goals for the subject,
discussing and designing curriculum, preparing lesson plans, teaching students together, and evaluating the results (Buckley, 2000). Two or more teachers can work together effectively to provide all possible facilities for the learners to learn. Collaboration among team teachers is a unique teaching style through which knowledge and skills can be imparted (Jang, 2006). The teachers involved in team teaching benefit more than the other teachers as team teaching allows joint efforts and mutual adjustments (Jang, 2006; Sundarsingh, 2015).

RESEARCH DESIGN

Mixed-Method Design

The study used sequential explanatory mixed-method design that combined qualitative and quantitative methods. In this study the quantitative approach basically involved the collection and analysis of questionnaire data, whilst the qualitative dimension allowed for consideration of interview data.

Population and Sample

The study focused on six Fijian secondary schools (two urban, two rural and two remote schools) which had a total of 43 Mathematics teachers. All the 43 Mathematics teachers completed the questionnaire from which 29 were male and 14 were female. In addition, from the 43 teachers who filled the questionnaire, nine consented to be interviewed. The teachers who were interviewed were a mix of urban, rural and remote teachers. The interview participants consisted of Mathematics teachers who were no-post holders, heads of department (HODs) and school administrators (Principal/Vice-principal/Assistant principal). From the nine interviewees, seven were male and two were female.

Data Collection and Analysis

Data collection utilised questionnaires and semi-structured interviews. The questionnaire for the study on PLC was adapted from Vanblaere and Devos (2016). The questionnaire had three parts. The first part requested for demographic details, the second part asked of their perceptions using a 5-point Likert scale: 1 (strongly disagree) - 5 (strongly agree) and the third part captured teacher’s reports of their current usage of the practices listed in part two, again using a 5-point Likert scale. With respect to this aspect the scale ranged from 1 (never) - 5 (always). This study utilised the Qualtrics online survey platform to administer the questionnaire.

From the 43 Mathematics teachers who completed the questionnaire, nine took part in an hour long semi-structured interview. With the permission of the participants, the interviews were recorded on a digital recorder to ensure accuracy. Descriptive analysis was carried out for the questionnaire data using SPSS version 24 where the scale percentage frequencies for each item was calculated. The interviews were analysed using a thematic approach using open coding, axial coding and selective coding for the development of themes.

RESULTS AND DISCUSSION

Using the data obtained from the questionnaire, the scale percentage frequencies were computed of the Mathematics teachers’ perceptions and practices for the sub-themes under de-privatised practices. Their questionnaire findings were further validated by the interview responses.

Being Observed

Table 1 presents the percentage frequencies for each scale for the sub-theme ‘being observed’.
Majority of the Mathematics teachers (62.8%) felt it was important to invite colleagues to observe your classroom instruction. However, the Mathematics teachers’ practices revealed that 53.5% never practiced it. This was further validated by the interview responses.

*The close colleagues can observe and give critical feedback which other colleagues or leaders may not be able to do it. However, we hardly get time to do such things due to our workload and also culture is such that teachers are bit reserved. In Fiji schools mostly HODs and admin observe classes to assess teachers. (F T3)*

The Mathematics teachers had revealed that it was a good idea to invite colleagues to observe classroom instruction; however, due to the school culture and the workload teachers were hardly involved in such activities. The results established that only the HOD’s and the administrators of the school get a chance to observe teachers’ classes. The teachers who were non-post holders were not given any opportunity to observe classes. This practice was not helping new teachers.

The quantitative and qualitative analysis has established that majority of the Mathematics teachers in the schools perceived that de-privatising the classrooms was important and would help in enhancing teachers’ instructional practices; however, the results revealed that currently it was little in practice. Most Mathematics teachers perceived ‘being observed’ was important; however, more than half of them had never practiced it.

The current norm was that classes were being observed by the HODs and the administrators to assess teachers. Due to such practice the teachers are bit reserved to go against the school culture; hence, hardly invite colleagues to their classrooms. This supports Hiebert, Gallimore, and Stigler (2002) and Stigler and Hiebert (2009) who avow that teachers are used to the norm of individualist tradition. However, as for the past century the tradition of individualised teaching has not helped to sustain teachers’ professional growth, a cultural change through de-privatisation of classrooms could be the way forward as asserted by DuFour and Eaker (1998) and Stoll et al. (2006).

**Team Teaching**

Table 2 presents the percentage frequencies for each scale for the sub-theme ‘team teaching.’

**Table 1. Percentage frequencies**

<table>
<thead>
<tr>
<th>Sub-theme</th>
<th>Perceptions &amp; Practices</th>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Being Observed</td>
<td>Perceptions</td>
<td>43</td>
<td>9.3</td>
<td>16.3</td>
<td>11.6</td>
<td>46.5</td>
<td>16.3</td>
</tr>
<tr>
<td></td>
<td>Practices</td>
<td>43</td>
<td>53.5</td>
<td>34.9</td>
<td>7.0</td>
<td>4.7</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**Table 2. Percentage frequencies**

<table>
<thead>
<tr>
<th>Sub-theme</th>
<th>Perceptions &amp; Practices</th>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team teaching</td>
<td>Perceptions</td>
<td>43</td>
<td>2.3</td>
<td>7.0</td>
<td>11.6</td>
<td>37.2</td>
<td>41.9</td>
</tr>
<tr>
<td></td>
<td>Practices</td>
<td>43</td>
<td>34.9</td>
<td>46.5</td>
<td>14.0</td>
<td>4.7</td>
<td>0.0</td>
</tr>
</tbody>
</table>
The data in Table 2 reveals that majority of the Mathematics teachers (79.1%) had positive perceptions about team teaching. However, 34.9% of Mathematics teachers never practiced it. This was further validated by the interview responses.

We hardly practice this in the first two terms. But in the revision class which is in the third term when the syllabus is complete we do help students in groups. We have 40 or more students in a class so when two teachers teach one class the ratio is reduced by half. Team teaching is effective for revision classes. (B T2)

As for ‘team teaching’, the analysis of the data revealed that Mathematics teachers favour team teaching as it reduces the student-teacher ratio. Teachers have strongly acknowledged that they are able to help students learn better through the collaborative experiences of team teaching which supports Buckley’s (2000) claim. However, it was found that there are quite a number of teachers who never practiced team teaching even though they believed it could be very helpful in improving students’ performance.

Some of the reasons for the non-practice were teachers’ work load and compact coverage. The Mathematics teachers’ comments affirmed that team teaching only happens in the revision classes which was basically in the third term after the coverage was complete. Teachers believed that through team teaching with colleagues, they were able to work cooperatively to help students learn better which is consistent with Sundarsingh’s (2015) claim. The results acknowledged that the students benefited mostly from the dominant form of de-privatisation of team teaching which supports Sundarsingh’s (2015) findings.

Observe

Table 3 presents the percentage frequencies for each scale for the sub-theme ‘observe.’

<table>
<thead>
<tr>
<th>Sub-theme</th>
<th>Perceptions &amp; Practices</th>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observe</td>
<td>Perceptions</td>
<td>43</td>
<td>7.0</td>
<td>11.6</td>
<td>9.3</td>
<td>51.2</td>
<td>20.9</td>
</tr>
<tr>
<td>Observe</td>
<td>Practices</td>
<td>43</td>
<td>58.1</td>
<td>34.9</td>
<td>4.7</td>
<td>2.3</td>
<td>0.0</td>
</tr>
</tbody>
</table>

According to Table 3, majority of the Mathematics teachers (72.1%) felt it was important to observe other teachers. However, 58.1% of Mathematics teachers never practiced it. This was further validated by the interview responses.

Yes, it is important. In Fiji it doesn’t happen. The leaders do get a chance to observe other teachers but the new teachers who are not post holders don’t get a chance to observe other teachers. I feel it is unfair. They are new, so they are more in need. (C HOD)

The analysis of the qualitative data highlighted that the novice teachers were sometimes deprived from learning through observing their seniors due to the school culture. The Mathematics teachers believed that school culture could change through the support of the administrators. There needs to be more awareness on the benefits of such practice. Such cultural change in the schools could largely benefit the novice teachers as teachers will be able to learn from their seniors as asserted by Mohan (2016).

Overall the data analysis revealed that there was a substantial difference in the teachers’ perceptions and practices. Teachers were positive about the benefits of opening their
classrooms to colleagues; however, they had little opportunities to experience this. Looking through the PLC lens, it can be alleged that through de-privatisation like observation and team teaching, teachers could indeed improve their instructional practices through engaging in collaborative learning where teachers’ colleagues could come together to actively learn and reflect on their practice (Mitchell & Sackney, 2009). However, this requires teachers to genuinely engage in learning with other colleagues in the school and be a firm believer that it is the way forward.

The results indicated that expertise, time, and school culture are essential for effective PLCs. The findings strongly accentuate the importance of the leadership support; however, it affirms that many teachers value the feedback of their close colleagues more than that of the leaders. Sometimes the school administrators lack subject knowledge to develop the skills of instruction needed for teachers. Hence, the support of subject expertise is critical for teacher improvement.

CONCLUSION

De-privatisation of classrooms seems to be one of the useful strategies Mathematics teachers could employ to nurture professional learning and promote improved teaching in schools. However, currently in Fiji it is hardly practiced; hence, could be one of reasons for low achievements in Mathematics. Teachers should be encouraged to engage in classroom observations and team teaching. Class observation could be highly beneficial to teachers if close colleagues are involved as they could receive critical feedback from those with whom they feel comfortable.

HODs in comparison to school administrators seem to be the more suitable people to cultivate the effects of de-privatisation particularly inside the classroom to support teachers improve their instructional practices. However, de-privatisation experiences need to be embedded within a carefully resourced school plan and has to be driven by the school leadership otherwise work load and school culture could be a challenge.

Even though the scope of this study was limited, being focused on Mathematics teachers of six Fijian schools, the outcomes from this research could provide policy makers and administrators with valuable insights into importance of Mathematics teachers’ de-privatised practices and how to best accommodate into educational policy development.

REFERENCES


INTEGRATING STEM AND THE MATHEMATICS ENRICHMENT PROGRAM: A TEACHER'S STORY

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ABSTRACT

Reason for this study: This is a story about Mathematics and STEM, presenting a successful case of school-based program “PROGRAM” integrating STEM into a mathematics enrichment program.

Aim: The aim is sharing the second author’s successful story of integrating a STEM component into the school curriculum by extending the mathematics enrichment program in his school.

Design: The study applied the ethnographic case-study approach with the second author as a participant researcher. Special consent was obtained from the school principal to access the school data, which includes, minutes of school meetings, all the teaching materials and student work and video clips, relevant reports. The storyline was built upon the second author’s presentation of “S.T.E.M. in Mathematics” on the Joint School Teacher Development Day in 2017; supplemented with analysis of relevant school data and additional information provided by the teacher.

Findings and discussion: STEM has been integrated into the existing school-based enrichment program in the school since 2015. The presentation of the findings is built on the emerging themes: the rationale of STEM in the school, a school strategy encompassing the changes that happened in the classrooms, introducing the problem solving model in the mathematics lesson (the example of the topic “the net of a cube”), other topics in mathematics (A Big Data experience), Math helping the students exploring STEM (the topic of “sound”).

Conclusion/Implication: The case gives an example for the importance of equipping students with mathematics in order to help the students having a good harvest in their STEM experience.

Keywords: STEM, mathematics, enrichment, problem solving, Makers, sound

1. INTRODUCTION

This is a story about Mathematics and STEM. Despite the globalisation of the promotion of STEM, there seems insufficient discussion for how mathematics may contribute to the students’ learning of STEM, for example, there was uneven distribution of regular paper presentation in the 2014 STEM conference in Vancouver and there was only 16% devoted to mathematics in contrast to 45% science (English, 2016). Fitzallen (2015) commented that it is easy to find reports of how STEM benefits the learning and teaching of mathematics but there are few addressing how mathematics may benefit the learning of other STEM disciplines. This paper will attempt to make a contribution to this gap, by presenting a successful story of a school-based integration of STEM in the mathematics enrichment program.
2. THE AIM OF THE STUDY

In line with the worldwide growing awareness of the importance to the education of Science Technology Engineering and Mathematics (STEM), the Hong Kong Government in the 2015 and 2016 Policy Addresses pledged promote STEM education and encourage students to pursue the study of STEM–related subjects. With respect to learning and teaching resources, the Hong Kong government has provided a range of strategies including the encouragement for schools to develop school-based STEM curriculum (Curriculum Development Council, Hong Kong, 2015). The aim is sharing the second author's successful story of building the school-based PROGRAM program by integrating STEM into the mathematics enrichment program in his school.

3. DESIGN OF THE STUDY

The study applies the ethnographic case-study approach with the second author, the co-author as a participant researcher. The second author, the key teacher responsible for the design and implementation of the school program PROGRAM, is an enthusiastic mathematics teacher with a passion for learning. The second author was the person-in-charge who designed and taught the school-based enrichment program launched in 2011, later integrated with STEM to form the PROGRAM program after 2015.

Access of data: Special consent was obtained from the school principal to access the school data, which includes, minutes of school meetings, all the teaching materials and student work and video clips, relevant reports.

Analysis: The storyline was built upon the second author’s oral presentation title “S.T.E.M. in Mathematics” on the Joint School Teacher Development Day in 2017; further analysis was supplemented with the emerging themes highlighting the case development and features with the insertion of relevant data of student work and additional information provided by the teacher. The emerging themes in the storyline were: the rationale of STEM in the school, a school strategy encompassing the changes that happened in the classrooms, introducing the problem solving model in the mathematics lesson (the example of the topic “the net of a cube”), other topics in mathematics (A Big Data experience), Math helping the students exploring STEM (the topic of “sound”).

4. FINDINGS AND DISCUSSION

The STEM curriculum has been integrated with the existing school-based enrichment program in the school since 2015.

4.1 The rationale of STEM in his school?

Following the governments’ promotion of STEM reform initiatives, the school decided to develop its own school-based STEM program (known as PROGRAM ). The second author was the teacher-in-charge of the PROGRAM program. For the period of 2011 to 2015, the school had developed an mathematics enrichment curriculum program with a progressive model, kicking off with only a class of 30 high-ability primary 5 (Grade 5) students in 2011, later developed to a 3-year program for the high-ability group of primary 4 to 6 students (Grade 4 to 6) attached to the regular mathematics curriculum. According to the teachers’ summary, the main strategies of the enrichment program were: compact and fast learning
pace, enrichment topics for a board knowledge bases and interest, extension of existing topics in the regular curriculum for advanced thinking skills and introducing activities in realistic contexts; the key elements in the program were high order thinking, inquiry-based learning and creation of “thinking space” (to provide students’ opportunities of thinking or communicating their ideas). The mathematics enrichment programs had been celebrating success and well recognised by parents and students, hence, it was important that the new STEM component would built upon the established strengths.

What is the rationale for STEM? From the school perspective, what they wanted to achieve was ultimately nurturing “Makers”? Why? For in today’s society with prosperous growth of knowledge, every individual might discover or invent something. In the preamble, the teachers in the school raised a question: “Do we want our kids to become workers in the assembly line or real problem solvers in the community?” They believed that the latter was what the citizens of the future needed; hence, they set their aim to be helping their students be real problem solvers. How to achieve this aim?

In building the program PROGRAM, the teachers adapted the Maker concept with a belief that the nurturing of Makers should be that of helping students become good problem solvers, thus going beyond the experiences of assembling of a toy from parts. Contrasting the existing mathematics enrichment program and STEM, their characteristics were compatible with each other. In the implementation, the STEM curriculum was implemented for the whole of primary 6 (Grade 6) after their completion of the enrichment program. Some relevant topics in the mathematics enrichment program, which originally consisted STEM elements were modified, and some new topics were developed.

As a result of its origin, the topics naturally put more demand on applying mathematics. Also, the gender issue was considered in choosing the topics. According to the teacher, “Though some girls might not like mathematics, while choosing the topics carefully, the girls also developed an interest in STEM”. The topics of students’ STEM projects included: Sound, Traffic light, Landing Device.

4.2 A school strategy for STEM

There were a few changes that the teachers wanted to happen in the lessons; hence, they built a school strategy for STEM encompassing the changes:

1. Creation of “thinking space” to provide more opportunity for student thinking and communication of their ideas.
2. Say “Yes” to hands-on experiences: This was important for some topics, such as, shape and space, it was not feasible without hands-on experiences. In the teacher’s words, “If the students had no hands-on activities, many of the students’ ideas might become only ‘soldiers on the paper’ or even ‘empty-talk’”.
3. Provision of “trial-and-error” opportunities: Via trial-and-error, the students would learn the meaning of fair test and the key issues in their trials. Such ability would help them solve problems with a systematic approach in future.
4. Introduction of Polya’s problem solving model (Polya, 2014): For providing a guidance for the students making trials systematically, Polya’s problem solving model was introduced. Most students would know the four steps: understanding the problem, making a plan, carrying out the plan and looking back. Some high ability students might be using this model. However, some students might not know how to decompose a problem into manageable sub-problems; thus, when they came across a huge problem such as a project, they would not know how to start. In the traditional practice, students often mostly experienced the last two steps, that is, they were asked to carry out the job and checked whether it was
correct. In fact, there was little opportunity for them to really make a plan, such as, to query whether a theory in science was true or not, to raise the questions: “Have I any methods to test it?” Hence, the second author planned to do some more in his design to let students experience the whole model of problem solving and made a conclusion based on this.

4.3 Introducing Polya’s Problem Solving Model in mathematics lessons (the topic of “the net of a cube”)

Problem solving was a very important part in the design of the STEM lessons and for taking advantage of the existing mathematics enrichment program, PROGRAM. It also embraced the students’ solid mathematics knowledge and skills. The topic “the net of a cube” is used in this section to illustrate this aspect.

The topic “the net of a cube” was taught in primary 4 in the mathematics curriculum in Hong Kong and the teaching in most schools only asked students to know the net of a cube, sometimes this might end up with rote memorisation of the facts. When the second author designed the lesson, he modified the objectives of the lesson to “Find the number of possible nets and a systematic way to count and draw all the possible nets of a cube”; and he purposefully designed the lesson to bring the student through the four steps in Polya’s problem solving model.

STEP 1: Understanding the problem: What does it mean by different nets? Are reversed figures different? Are rotated figures different? They need to clarify these questions in the differentiation of the same or different figures.

STEP 2: Making a plan: Finding the major categories: 4 in a row, 3 in a row, 2 in a row, …. etc. They need to know that only nets belonging to these categories can form a cube, whereas, other types do not work.

STEP 3: Carrying out the plan: After the categorisation in the planning, the drawing and counting become systematic and relatively simple. Without this systematic overview of the nets, the task will become random trials and this will be very difficult.

STEP 4: Looking back and Extension: How far can they go? For higher ability students, they may explore the case of the cuboid and they will notice the similarity and difference between the cube and the cuboid. Applying the concept of rotational symmetry, they can calculate the number of nets for a cuboid was 54. In the implementation of the lesson, they did not need to draw all. They only had to give the teacher the formula and explain the principle how they get it. This was the main beauty, where they learned to find principles in the patterns and make their own conclusion. (Figure 1)

Figure 1. Students’ work for the topic “the nets of a cube”
Extension to making their own SOMA CUBE: The SOMA CUBE puzzle had seven parts. The teacher gave the students some guiding questions:

- Can they find the seven parts?
- Is there any relationship between the parts?

![Figure 2. Investigating the SOMA CUBE](image)

After finding the L-shape pattern, they were further prompted: Would there be any patterns in the nets? Then the teacher asked them to work in groups and to draw the net of a part themselves. They could choose a part to draw the net according to their ability. After gathering all the nets from all groups, they were further asked to discover the relationship among the parts and make a simple conclusion.

After the scaffolding discussion, the students were able to draw a more complicated net. Teachers printed out their own nets so that they could make their own toy. The students all found that the lesson was a rewarding experience for they owned the process of problem solving, the process of discovering the pattern and creating their own toy. The purpose of such arrangement was for the creation of “thinking space”, the provision of opportunity for thinking, explaining and communicating their ideas further (Figure 2).

4.4 Other topics in mathematics: A Big Data experience

Handling big data became popular and students would have an interest in this. The data provided in the exercises in the traditional textbooks were usually not authentic and boring. Hence, the second author created a big data experience for his students by asking them to compare their Body Mass Index (BMI). They collected their own data of height and weight using the Google form, and in a short time they collected more than a hundred authentic data the second author purposely gave them the BMI formula for adults, and thus they found that all the results were below the standard. The students were then asked to discuss a number of questions related to the topic:

- Data collection: How to collect the data? What is privacy? How to seek consent politely? How to use the Google form?
- Analysis: What is the range for healthy BMI? Why are most students under the standard? Will there be a different BMI for Asian people? Will the formula be wrong? Can the results be adjusted by a factor? Will there be any gender difference?
- Conclusion: Are there any formulas for children BMI? How reasonable are their interpretation and adjustment?
4.5 Math helping the students exploring their ideas in depth

They also attempted to integrate other subjects into the Math lessons to give them the experience that math could help their investigation for different topics and the “what-if” question often gave a creative element the process of exploration. For example, What if the wheel of a car is not a circle? What may be the angle for shooting the cannon ball? How does GPS work? How does math help finding out the answers?

An example: The topic of “Sound”

The topic “sound” was first created and tried in the high-ability group in primary 6 in the old enrichment program; now revised implemented for all the primary 6 students in PROGRAM. The investigation of “sound” was a major part of PROGRAM; it last for about 12 to 15 lessons, with one lesson every Friday, starting in May or early June, after the class had finished the regular mathematics and the old enrichment mathematics component.

In addition to knowing the facts about the transmission and frequency of sound, they learned to raise many questions. The students had to design their own experiments and methods to find out the answers. Some questions were: Is sound really transmitted through air? Besides the vacuum test, are there other methods? Can we find methods to measure the speed of sound? How may water in the glass affect the sound produced? Will there be a formula? For example, to find out: How true is the statement ‘the range of human hearing is 20Hz to 20,000Hz’? They invented tests and collected data from different people including members of their family. They then discussed the trends of the line charts and drew conclusions.

Finally, they were asked to do a project to make an instrument and play a song with their own instrument. Figure 3 showed how the students applied their mathematics to find out answers for their questions about the frequency and transmission of sound, and Figure 4 showed how mathematics helped them design their musical instrument.

To make the musical instrument, they needed to decide how to cut the long brass pipe into pieces of different lengths based on their own experiment; there would be a lot of waste of materials and frustration if they did guess-and-check only. Eventually they solved the problem by drawing a broken line graph to find the relationship between the length of the brass pipe and the musical note, and they proudly presented their ideas to the class in the project presentation.

Figure 3. Some examples of the students’ work for the topic of sound
4. CONCLUSION AND IMPLICATION

For the design of integrated STEM education initiatives, Honey, Pearson and Schweingruber (2014) suggested that students’ knowledge in individual discipline must be supported. The study gives an example of a school-based integrated design for implementing STEM education drawing support from an established mathematics enrichment program in the school. To conclude, Math enrichment and STEM provide opportunities for the students to exert their talents and potential, a venue for students to show their high order thinking, collaboration and communication ability.

REFERENCE


EXPLORING STEM CONTENT AND PRACTICES BY BUILDING RUBBER BAND MUSICAL INSTRUMENTS IN MIDDLE SCHOOL

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ABSTRACT

This paper presents a newly developed musical instrument building activity and examines in depth an introduction activity designed to introduce students to science content and engage them in scientific inquiry practices. Students were first introduced to contact microphones, a tool to help them more meaningfully engaging with rubber bands as musical strings by amplifying their sound. In groups, they were then asked to determine how the length, thickness, or tension of a string affects the pitch it plays. This study follows a group of four middle school students as they engage in this activity. Specifically, we look for evidence of learning about science content related to sound as well as engagement with science and engineering practices, all key features of learning standards in primary and secondary education. Examples from the case study suggest learning about the physics of vibrating strings and meaningful engagement in science practices, with little evidence showing learning about the movement of sound through matter. Features of the experiment design provocation offer broader implications to designers of STEM learning environments.

Keywords: Science of Sound, Music, Experiment Design, STEM Content and Practices

INTRODUCTION

The production and perception of sound plays a major role in the day to day life of nearly everyone, as it is one of the primary modes of communication between people. Vibrations and the propagation of sound waves are key features of science learning standards at all ages, from relating noise to vibrating matter in pre-K to understanding frequency, period, and wavelength in high school (Massachusetts Department of Elementary and Secondary Education, 2016; NGSS Lead States, 2013). These standards also emphasise the importance of giving students the opportunity to engage with scientific inquiry and engineering design throughout their elementary and secondary schooling. In the learning goals, the institutions recognise that “science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge” (National Research Council [NRC], 2012, p. 27).

I developed a novel activity where students design and build rubber band musical instruments using a laser cutter, with the goals of having students (a) engage with authentic scientific inquiry practices, (b) learn about content related to the science of sound, (c) apply science knowledge to engineering design, and (d) learn new digital fabrication skills. As part of this integrated engineering design activity, I challenged students to come up with a scientific experiment to determine the way rubber bands control pitch. This paper presents the methodology for this intro activity, showing a case study of four 7th and 8th grade students.
going through it. I evaluate their productive disciplinary engagement with scientific inquiry in general and the physics of vibrations in particular (Engle & Conant, 2002).

BACKGROUND

As humans have incredibly sensitive sound sensors attached to their head at birth, no technology is needed to make observations about sound, enabling philosophers in ancient Greece to begin studying and understanding how it works. Legend says that Pythagoras experimented with string vibrations around the 6th century BCE, determining that shorter, less dense (thinner), and tighter strings produce higher pitched musical notes (Lindsay, 1966).

STEM education researchers have examined the practices that are a part of authentic science and studied the best methods to introduce them in classrooms. Engle and Conant (2002) argue that the most engaging science learning environments point out a problem, give students authority to investigate it, hold them accountable to their peers, and provide them resources to do all of this. Manz (2015) discusses the importance of having students engage with the notion that science involves an iterative process of coming up with a hypothesis, receiving some unexpected results as you try to test it, and refining your methods and ideas to accommodate this pushback.

Researchers have studied how students learn about the science of sound when engaging in hands-on instrument building activities with promising results (Anderson, 2017; Wendell, 2011). In a larger study examining the learning outcomes of engineering-design based curriculum, Wendell and Rogers (2013) find that students gained more science content knowledge about animals, material properties, simple machines, and sound when taught with a LEGO engineering curriculum as compared with the status quo. However, sound was the one content area of the four studied where the learning gains from the engineering design lessons were not significantly more than the status quo. Additionally, reflecting on a week long musical instrument making intervention in Denmark with students from pre-K through 8th grade, Lieboreth (2015) writes that many students built percussion instruments without incorporating the “more academic information of acoustics”.

These findings suggest the need to develop a new learning environment that can effectively teach students science content about sound while they engage with scientific inquiry and engineering design practices. Speculating that students’ tendency towards percussion instruments was due to the clarity of the sounds they could produce, I decided to limit the scope of the activity to rubber band instruments and introduce students to contact microphones and amplifiers. The motivation for these choices was to increase engagement with musical strings by allowing students to more clearly hear rubber band vibrations as musical notes.

METHODOLOGY

To begin the workshop, I introduced students to the contact microphone by demonstrating how they only amplified vibrating matter, speaking into the mic with no effect then pressing it to my vocal chords to hear my voice amplified. Each table had clipboards, rubber bands, and sticks, and I told the class they could tape the contact microphone onto the clipboard in order to amplify the sounds produced by the vibrating rubber bands. They were then given five minutes to “play around and see what you can do, see what sounds you can make”.

At the end of this open exploration, I brought the group together to discuss sound and what produces it, asking them to think deeply about what vibrations are. After focussing the
discussion on how strings vibrate, I challenged the groups to “make an instrument that can play three different notes” in five minutes. The goal of this activity was for students to explore what different notes rubber bands could make and start wondering what caused these differences.

After they created these first instruments, I lead a discussion in which the students said that pitch was the main difference between the sounds produced by the rubber band strings. By asking about how the vibrating strings themselves were different, the class landed on the length, thickness, and tension as the rubber band’s physically controllable factors. By pinching a band between two fingers in either hand and plucking it, then pulling my hands apart and plucking it again, I demonstrated how all three of the physical variables were coupled (the string got longer, thinner, and more tense at the same time). This example was used to begin a discussion of the scientific method, reminding students how one variable need to change at a time to determine its effect on an outcome.

Each group of students was then challenged to design an experiment to investigate how the length, thickness, or tension controlled the pitch played by a rubber band. After roughly 7 minutes, each group presented the experiment they developed and how they thought their variable affected the note produced by the string when plucked. As a class, we came up with conclusions about how each variable could be controlled to produce higher pitched notes. The case study presented below analyses a group of students during this portion of the activity.

Following this intro activity, students were introduced to the challenge they would spend the next two full class periods on; design and create a musical instrument by laser cutting plywood. After a brief introduction to the software used to design for the laser cutter, students were free to follow their own creative process for the remainder of the activity.

**Research methods**

This research pilot was conducted in the makerspace of a pre-K through 8th grade private school (20% of students on financial aid and 92% of faculty with advanced degrees). The musical instrument making activity was conducted over the course of three 1.25 hour meetings of the 7th and 8th grade arts elective. The data presented here focuses on a group of four students (one boy, three girls) as they engage in the experiment design part of the activity, starting roughly 20 minutes into the first class and lasting 10 minutes.

A descriptive case study approach was used for this paper as it was the first research pilot of the intervention (Hancock & Algozzine, 2006; Merriam, 1998). Using video and audio data, I present sections of transcript, still images of their work, and observations captured in field notes. The case study is analysed to look for examples of students engaging in scientific inquiry. Their productive disciplinary engagement is measured by student’s emotional investment and self advocacy for their ideas.

**RESULTS**

The group in this case study consisted of Rob and Linda on one side of the table, and Kate and Sara on the other. During the first activities, when they explored the different sounds the strings could make and created an instrument that could play different notes, the group spent a good amount of time exploring the contact microphones. Some discussion took place about whether the placement of the mic on the clipboard made a difference. They had also pointed out the different “stretchiness” and “thickness” of the rubber bands by the end of the instrument building activity.

This group was asked to “explore how tension affects... the pitch that the rubber band plays” in five minutes. Sara started by saying “I don’t know how to do tension, cause by
pulling it, that’s what tension is, but you’re also making it longer and less thin”. Linda agreed, saying “we can’t just make it longer, cause it’s also going to affect the thickness”. As the pairs on each side of the table were focusing on their instruments, Kate said “guys we’re supposed to be doing it as a table”. Rob responded “okay, but we don’t know what to do, we’re thinking, we’re brainstorming”.

After a couple of minutes, Linda and Sara starting organising the assorted rubber bands on the table by thickness and length, trying to find two that were the exact same. Rob, still focused on the contact microphone, suggested that they use the two mics at the table as a tool for testing different setups, “one of ‘em tighter, and one of ‘em less tight”. He asked “how do we measure tension without changing the length?” which started the following argument.

**Rob:** Guys, how do we measure tension without changing the length? [looking at the facilitator]

**Facilitator:** You tell me

**Kate:** We find, oh here it is, two rubber bands that are exactly the same, and do something...

**Linda:** No but the thing is, if you make them exactly the same, it’s still going to get wider. You have to make... have one that’s like, if it’s this thickness at this tension, then it’s this thickness at the...

**Sara:** No but if we, if you make it like this [pinching rubber band with each hand], and then we make it like this [stretching the band], it’s still the same rubber band, still the same length...

**Kate:** It’s also length.

**Linda and Rob:** With different tension.

**Sara:** No but this...

**Kate:** It’s the same length.

**Linda:** No it’s not because it’s the same length as the other one.

**Sara:** No but this is longer than this [stretching two rubber bands next to each other].

Following this discussion, Rob asked me “do you mean length by when it’s all stretched out, or when it’s just”. I again responded “you tell me”. However, after Rob expressed some frustration, I pointed out that the rubber band only really vibrated between the two sticks, so that was the length that mattered in this case. Rob immediately had an idea, pointing to the instrument he and Linda created in the last activity, and how they taped the bands in the back in order to change how tight they were on the top over the sticks (Figure 1a).

The group continued debating whether or not the same rubber bands would be the same thickness when stretched with different tensions across the same length. In this interaction, the group members began talking over each other, cutting each other off, and raising their voices slightly. Sara said “if you find two rubber bands that are the same thickness, it doesn’t change”. Linda and Rob pushed back, with Rob saying “it does because you’re pulling it, but that is the best we could do”. Linda then took the floor, saying “can I just explain my idea first”. She held a thick and short rubber band, stretched it to the size of a thin and long rubber band, arguing that they were the same thickness and length, just different tension, because the smaller band got thinner as it was stretched (Figure 1b).
They decided to split into two groups, with Sara and Kate performing the experiment with two of the same rubber bands and Rob and Linda performing the experiment with a short, thicker rubber band and long, thinner rubber band. By the end of the experiment design part of the activity, before they are asked to present, the two groups compare results, agreeing that more tension causes the pitch to become higher. The following transcript is from the presentation of their experiment to the class.

Sara: We did two experiments, but got like the same result. For the first one, we did... the back... [Kate flips over the clipboard] it was the exact same rubber... or the same type of rubber band. But one of them we made tighter by...
Kate: Taping it in the back
Sara: Taping it in the back, and one of them we made loose by just putting it around.
Kate: And then the one that was tighter was higher, and the one that was looser was lower.
Facilitator: So the one that was tighter was higher, and the one that was looser was lower. Okay. Did everyone agree with that?
Rob: Yea we had like a similar...
Linda: Yea, but this one was a lot longer than this one, and then... And this one fits around it without putting that much tension on, and this one you have to stretch it really far, put tension on it, and then it's basically the same width, or thickness, and then... the one with more tension was higher.

DISCUSSION

This case study offers promising results on the effectiveness of having students design scientific experiments as an introduction to a larger musical instrument design activity. The contact microphones seemed to enable students to more deeply engage with the rubber bands as musical strings. During the open exploration activities in the beginning, the group spent a significant portion of their time focused on the mics, arguably going through scientific inquiry practices to determine how they work. As they engaged in the experiment design, the group only used the mics to help them hear the difference between the notes that the different strings produced, a process which would have been much more difficult without the amplification.
Based on Engle and Conant’s (2002) criteria for productive disciplinary engagement, this case study suggests that the students made intellectual progress over the course of the activity. The emotion shown in their voices during the argument over tension and thickness, as well as Linda and Sara’s self-advocacy for their ideas about the experiment show deep engagement in the task. The complexity of the discussion they were having from the beginning to the end of the activity, both about the content related to vibrating strings and about their experimental design, clearly increased. These data suggest this provocation was effective at productively engaging them with the disciplines of string vibrations and scientific inquiry.

There was some hope that the contact microphone would also enable students to achieve a deeper understanding of how vibrations travel through materials, as they could explore different pathways of transmission from the rubber band to the clipboard. While the group had some discussion about how the placement of the mic affected its performance, there was no evidence of intellectual development with relation to how sound travels through different forms of matter. Future iterations of the activity could more directly address this content by asking students to focus on how the microphone works.

CONCLUSIONS AND FUTURE WORK

Early results from this pilot study of a newly design STEM activity suggest increased effectiveness at teaching content related to vibrating strings and engaging students in scientific inquiry practices. Two features which productively engaged students in this learning environment may have implications for designers of STEM activities; the way that the physical properties of the rubber band strings were inter-related in this provocation provided students with a clear entry point to designing the experiment and the introduction of the contact microphones allowed deeper exploration of phenomenon and increased productive disciplinary engagement. Future research will examine the entire musical instrument design activity across multiple cases, looking for evidence that students actively apply the science content learned in the introduction activities as they go through the engineering design process.

REFERENCES


ABSTRACT

We are currently engaged in an international collaborative project to implement and evaluate Professional Development (PD) to promote Inquiry-Based Learning (IBL) in mathematics and science. The rationale for the PD programme is underpinned by claims that IBL, through the use of digital technology and dialogic group work, can engage and motivate students. We are also aware that PD is not always successful in transforming teacher practice, and a key aim of our study is to determine the challenges and opportunities generated by the PD. The PD implemented in this study takes place in sixteen Qatari classrooms with eight mathematics and eight science teachers and their students from Grades 4 to 8. The teachers are supported by eight Qatari Professional Development Specialists (PDS). For the larger project we employ both qualitative and quantitative data within a comparison case study to analyse relationships between teachers’ perceptions of the challenges and successes in implementing IBL and the students’ attitudes to science and mathematics. In this conference paper, we present qualitative data from the pre-PD interviews with teachers and students. These data reflect divergent views in relation to their anticipations and concerns, and emerging themes are intended as a baseline for the comparison case study. In addition, these diverging views add to our understanding of the ways teachers and students adapt to new pedagogies within their existing belief systems.

Keywords: Professional development, teacher and student perceptions, inquiry-based learning, WebQuests, exploratory talk.

INTRODUCTION

There is an international consensus that an innovative economy in the twenty-first century prospers through Science, Technology, Engineering, and Mathematics (STEM), and Qatar, like many other nations, sees the promotion of STEM subjects as a priority in developing a knowledge-based economy. Their aim is to “strengthen K-12 and undergraduate programs in the fundamental sciences and mathematics” (Qatar National Research Strategy, 2012, p.2). However, many Qatari students become disengaged and disinterested in science and mathematics (Said & Friesen, 2013). Our international collaborative project, funded by the Qatar National Research Fund, aims to address this disengagement by implementing and evaluating Professional Development (PD) to promote inquiry-based learning (IBL) in mathematics and science with students, Grades 5 to 9.
Despite a substantial national investment in professional development initiatives in Qatar, concerns remain about the subsequent impact of PD on instruction (Said, 2016). In this project, the PD is delivered by Qatari Professional Development Specialists (PDS), using a programme that has been developed collaboratively between the research team and the PDS. Furthermore, evidence suggests that successful PD is practical and manageable, with sustained professional support in the classrooms (Supovitz & Turner, 2000). Hence, in this project, the PDS introduce practical didactic tools to encourage collaborative inquiry and provide ongoing in-class support. Whilst we are attempting to optimise the supportive and practical elements of the PD, we are aware that there may still be tensions in shifting practices towards IBL.

INQUIRY-BASED-LEARNING (IBL) IN SCIENCE AND MATHEMATICS

In this project, our interpretation of inquiry-based learning (IBL) stems from the idea of inquiry as “a process to seek for information, knowledge, or truth through questioning” (Chan, Lam, Yang, Mark, & Leung, 2010, p. 205). IBL is not seen as learning as doing, instead it is seen as posing real questions, and encouraging and investigating tentative answers (Wells, 1999). In conventional instruction, the teaching is one-way as a linear deductive monologic transfer from the unknown to the known. In inquiry, there is a dialectic cyclic interplay between the unknown and the known (Artigue & Blomhøj, 2013) in situations where students are faced with a challenge. There is a need for the teacher to act as organisers and facilitators rather than the instructor delivering the content. Hence there is the need to shift practice and this shift can present didactical stresses to both teachers and students as they move from existing classroom norms.

Furthermore, the disciplines present differing pedagogical perspectives. Science, as an empirical discipline, is generally seen to relate more readily to inquiry (Harlen, 2012). However, an interpretation of inquiry as learning as doing may mean teaching focuses more on the hands-on aspect and that inquiry is a process where students participate, rather than being the vehicle for learning. Mathematics, on the other hand, is more often seen as a deductive discipline, and mathematics inquiry is often synonymous with problem solving. Introducing inquiry into mathematics education suggests there is also an inductive, experimental component (Artigue & Blomhøj, 2013). This component may not be so readily recognised.

DIALOGUE AND DIGITAL TECHNOLOGY IN INQUIRY

Mansour and Wegerif (2013) proposed that learning in science and mathematics is about sense making in a context, and not just about acquiring content. Meaning is dependent on understanding in a broader social and cultural context (Wells, 1999). Hence, IBL becomes a way of working dialogically in classrooms to construct and re-construct knowledge between participants in specific contexts. Communication and sense making become key aspects of the interaction between teacher and student and among students. In order to support dialogue between students, strategies related to exploratory talk were introduced in the PD. Exploratory talk is defined as “a way of using language effectively for joint, explicit, collaborative reasoning” (Mercer, Wegerif, & Dawes, 1999, p. 97). In the PD, didactic strategies to encourage such dialogue are introduced to support students in working together to present tentative answers and to justify their decisions.

A further element of IBL relates to an authentic learning culture, and we draw on the use of digital technology and the internet as a way for students to investigate in authentic ways beyond their classroom. WebQuests present a practical and manageable tool to structure
the way students use web-based sources to inform their own ideas within an investigation (Salsovic, 2007). According to the creators of WebQuests, there are six sections: introduction, task, process, resources, evaluation, and conclusion (Dodge, 1995). The introduction is to inspire the students, and the process enables students to research answers to their questions.

These didactic tools relate to the development of IBL where students engage critically in asking and researching questions, presenting tentative answers, and engaging in constructive dialogue to make and justify decisions. The two tools can be used across both science and mathematics, and are also practical and manageable within classrooms. A key aim of the project is to determine if these two didactic tools can help support teachers and students in moving to IBL.

METHODOLOGY

Sixteen teachers (eight mathematics and eight science) from eight schools were asked to introduce the didactic strategies with one of their class of students. The classes ranged from Grades 5 to 9.

Eight PDS (four specialists in mathematics and four specialists in science) worked with the teachers. They presented initial workshops and provide in-class support at intervals across two school terms. For the larger project, we gathered both quantitative and qualitative data, and employ cross-case analysis to summarise, integrate, and combine findings of the students and teachers. We are in the process of collecting data, and in this short conference paper we present initial analysis from pre-PD interviews as an exploration of themes that could be used in the larger cross-case analysis to synthesise the evidence from the multiple case studies. The interviews were carried out with individual teachers and in student focus groups.

Themes relate to two main areas of teacher and student perceptions. The first area relates to teachers and students’ views of IBL within the two different subjects, science and mathematics. The second area relates to perceived stresses and challenges of the teachers and students as they anticipate introducing a new pedagogy into their classrooms. We use three of the challenge and stress factors identified by Grant and Hill (2006) to inform the themes within this area. The first factor is the recognition and acceptance of new roles and responsibilities, and the stresses teachers may feel as they give away the responsibility of learning to the students. A second factor relates to the comfort level of teachers and learners within the physical layout and dynamics of the classroom. The classroom environment may feel less controlled, and, hence, disquieting and uncomfortable for some teachers and students. A third factor, tolerance for ambiguity and flexibility, is concerned with social and emotional factors. Students no longer interact with content commanded by the teacher, and both teachers and students may not tolerate the level of ambiguity that arises. These thematic areas are used to analyse the teachers and students’ views, anticipations and concerns as they are about to introduce IBL into their classrooms.

RESULTS

The sixteen teachers had a range of teaching experiences from three years to twenty-two years. Schools are separated by sex in Qatar, and the classes of students involved in the project ranged from Grade 5 to Grade 9. All the teachers have at least a degree-level qualification, either in the subject area they are teaching or in education with a specialisation in the subject area they are teaching. All teachers expressed a high level of confidence in the subject they taught.
Views of IBL

All the science teachers referred to IBL as scientific method, to developing and testing hypotheses and to carrying out experiments. Three of the science teachers stressed the importance of directing the learning and giving students instructions on completing experiments. One science teacher referred to IBL as student-centred construction of knowledge through asking questions. Two mathematics teachers also referred to IBL as scientific research, and one teacher felt that inquiry was not possible in mathematics. Some mathematics teachers referred to inquiry as problem solving or statistical inquiry, and that teachers directed the solution strategies for students. Three mathematics teachers referred to student-centred exploration, authentic discovery, and to construction of knowledge, where learning differed from the memorisation of facts.

Students’ comments suggested that inquiry was more likely to happen in science in laboratory activities, with one student group stating that inquiry was not possible in mathematics. Students commented how science activities involved the teacher giving clear instructions in how to carry out experiments or that they observed the teacher carrying out an experiment. Students referred to problem solving in mathematics, where they followed the teacher’s directions. One group of students referred to inquiry as discovering information independently of the teacher.

Concerns and aspirations for developing IBL

Five mathematics teachers and three science teachers were concerned students would not accept new ways of learning. Mathematics teachers were concerned that the students would lack motivation in carrying out their own investigations. Another mathematics teacher referred to behavioural problems during group work. Three mathematics teachers and four science teachers expressed concern about meeting the learning objectives through inquiry. The teachers felt their role was to direct the learning for students. Five mathematics teachers and five science teachers were concerned about the students’ skills in investigating and discussing ideas. Some of these teachers felt the need to continue to conduct discussions, but others felt that with organisation and training they could encourage their students to engage in IBL.

Students gave contrasting perspectives in relation to learning through IBL. Several students felt they would like to discover learning themselves and become more independent. They saw a benefit in relying on their own thinking and learning from mistakes. Some saw that inquiry would be like learning in the real world and that they would understand the topics better. In contrast, some students preferred that the teacher clarified questions, gave explanations and directed them how to reach the solution in mathematics. These students felt that the teacher had the best ideas and that it was important to understand the teacher and to get the right answer. Some students also felt they would need guidance to understand the lesson and to carry out experiments in science.

Students gave contrasting viewpoints in relation to working in groups. Some felt they could help each other with difficult terms and share answers, whereas others were concerned about lack of interaction in sharing ideas and opinions. Some students referred to disruption over resources or domination of group discussions. Several students felt they would be embarrassed to talk to others as they might not have the right answers.

ANALYSIS AND DISCUSSION

The predominant view from both teachers and students, in relation to the two subjects, reflected the notion of science as an empirical subject and a lack of awareness of inductive elements of mathematics. Inquiry was often related to practical hands-on activities or to
problem solving, reflecting the notion of IBL as a process that students participate in. A minority of teachers referred to student-centred exploration, possibly suggesting inquiry as a vehicle for learning. More mathematics teachers referred to IBL in this way, perhaps because they were not relating to scientific methods. Comments in some student groups also acknowledged IBL as a vehicle for learning. Students referred to discovery, learning by themselves and relying on their thinking to understand better. These divergent results relate to those found in previous international studies in regard to the different disciplines (e.g. Artigue & Blomhøj, 2013; Harlen, 2012).

Regarding the challenge factors, several teachers felt a need to direct instruction in both mathematics and science classes and to give clear explanations and guidance for students. This sentiment was reflected by some of the student groups, where they preferred their teachers to give clear guidance. Furthermore, some teachers felt their students’ prior training and expectations might impede their ability to take on responsibility for their learning. Such comments suggested that the teacher had responsibility to control the process of learning, and these perceptions may lead to challenges in relation to new roles and responsibilities as teachers start to give away the responsibility of learning to the students.

Comments from some teachers suggested that they should be in command of the subject content to meet the lesson objective. They perceived the teacher as the main authority of learning. This perception was also reflected in some student groups, with the teacher having the best ideas. The move away from a conventional deductive monologic approach may cause stresses for these teachers and students as they move to the more ambiguous and flexible approach of learning within IBL. Some teachers may feel their students will not achieve in their learning, and some students might not feel prepared to work with tentative answers and solutions within group work. This lack of tolerance for ambiguity is contrasted with those students who were keen to take responsibility of discovery in their own learning and to learn from their mistakes.

There were less concerns about management and comfort factors by the teachers. One teacher expressed concern about potential behavioural issues and that this would challenge his skills of class management and cause discomfort for his students. However, several groups of students referred to issues in group work and expressed potential discomfort in their classrooms.

CONCLUSION

The initial analysis presented in this conference paper provides some understanding of teachers and students’ pre-conceptions and beliefs about introducing IBL in their classrooms. In particular, the analysis shows the divergent values about teaching and learning in the two subjects and perceived challenges within the roles and responsibilities within IBL. Previous studies have determined differences in teachers’ perceptions in relation to culture and national requirements (e.g. Engeln, Euler, & Maass, 2013). In this study all teachers are Qatari residents, the culture is homogenous, and teachers all face the external realities from the curriculum and reporting procedures within the Qatari education system. Nevertheless, the divergence is still present. There is little research on students’ views of inquiry and perceived challenges, and this analysis provides evidence that students also have divergent views.

Further analysis is required to relate these factors to age groups and to ability levels, and to link teacher and student views more directly in developing themes for cross-case comparison in the larger project. However, one key element of introducing IBL is how teachers and students can adjust their roles, perspectives of ambiguity and management of
new classroom practices, and we are more aware of the diverging views that might impact on these adjustments. It seems that, whilst access to materials and tools are important in professional learning, teachers and students’ views play a large role in determining how IBL is adopted (Anderson, 2002). In evaluating the PD, we will have the opportunity to investigate how teachers and students’ views, in relation to these factors, play a role in the adoption of IBL in each class.

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ACKNOWLEDGEMENT

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INTEGRATED COMPUTATIONAL THINKING AND MATHEMATICS THINKING: AN ANALYSIS OF TWO GEOMETRY ACTIVITIES

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ABSTRACT

This paper explores a branch of STEM/STEAM that uses computational thinking (CT) technologies and activities in classrooms. Current attempts to teach CT have focused on teaching the technical skills of coding to learners. Only a few harness these skills to meet epistemological, curriculum and pedagogical goals. In four elementary classrooms, students participated in computation thinking activities designed around specific mathematics learning goals. The activities involved application of selected CT tools to explore geometry concepts. The researchers studied written, interview and artefact data from the classrooms to answer the questions: What are plausible paths for integrating CT with mathematics thinking in grades 2-8 classrooms? What are the enablers and tensions of integrating CT with mathematics thinking? Activities for Grade 2 to 4 students were structured as exploration centres and the Grade 7 and 8 activities were structured as exploration centres as well as mini-projects. Moments from the classrooms that caught the researchers’ attention, critical moments, were studied including participants noticing mathematics concepts embodied or enacted by the CT tools. The findings suggest that selected activities, including path and polygon drawing, and maze activities enabled engagement on both CT and mathematics thinking. Analysing these activities, the paper focuses on concepts that student engaged in and how some of these were review, grade level, different, advanced, abstract or new concepts. Tensions were also evident such as the conceptual tensions in certain tools. The paper discusses implications of the study on the design of activities that integrate CT with subject-specific learning.

Keywords: Computational thinking, Computer programming, Coding, Mathematics, Elementary, Activity Design

INTRODUCTION

Computational thinking, programming and coding activities for children were originally adopted to use programming as a form of representation for learning mathematics and science (Papert, 1980, 1996). Educators, the community, and governments in several countries, are currently interested in engaging children and youth in computational thinking (CT) activities including programming activities and data practices. In the Canadian province where the study took place, CT is not currently integrated in the K-8 programmatic curricular as a distinct subject, rather it is taught in varied other learning contexts.

Berland and Wilensky (2015) observe that several current attempts to teach CT have focused on teaching the technical skills of coding to learners and novices. Moreover, only a few of these activities are harnessed to meet curriculum and pedagogical goals, and few take
place in classrooms (Wilkerson-Jerde, Wagh & Wilensky, 2015). This paper explores the potential for integrating CT with mathematics thinking in elementary classrooms.

Goals and objectives
The objective of the research reported was to study the integration of CT tools and activities in the teaching of school mathematics, and to specifically answer the following questions:

1. What are plausible paths—the activities—for integrating CT with mathematics thinking in elementary school classrooms?
2. What are the enablers and the tensions in the integration of CT and mathematics thinking activities?

THEORETICAL FRAMEWORK
Papert (1980) emphasised constructing of knowledge from active engagement with tools and with others. Papert based the theory of constructionism on research studies in which children and youth learned to program both “screen” turtles and “floor” turtles (Papert, 1980). Papert referred to the digital turtles as “the invention of ‘objects-to-think-with’, objects in which there is an intersection of cultural presence, embedded knowledge, and the possibility of personal identification” (p. 11).

Papert (1996) saw a promise in dynamic media to provide “a much richer set of new representations of” (p. 110) and “multiple connections with mathematical ideas” (p. 111). Papert argues that “learning consists of building up a set of materials and tools that one can handle and manipulate” (p. 173). Papert’s work informs studies on CT activities for learners as well as research on the use of physical and digital technologies in teaching mathematics.

This study is situated at the intersection of two literatures: Integrating CT tools and activities in school curricular, as well as tool-based instructional reform in mathematics education.

Computational thinking
From the learning theory of constructionism, Papert (1980) proposed that engagement with computer tools would be beneficial for students to learn. It is widely agreed that the construct, computational thinking (CT) was coined by Papert and popularised by Wing (2014). CT is currently defined in varied ways from a taxonomy of computer science contexts, including computational programming and computational data practices (e.g., Barr & Stephenson, 2011). Wing (2014) defines CT as “the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer – human or machine – can effectively carry out” (p.1).

In this study, CT is taken as an umbrella term that connotes computer science related competencies and concepts that might be of value to teach in non-computer science subjects. CT concepts draw on general concepts that, over past few decades, as Wing (2014) observes, have become fundamental principles in computing, information communication technology, informatics and other computer science fields.

The metaphor of CT as extending over the problem-solving process, which is also present in Wing’s (2014) definitions of CT, resonates with the interest in integrating CT in mathematics education. For Kalelioglu, Gülbahar and Kukul (2016), CT is about the entire process of problem solving from problem posing to assessing and extending solutions.
Tool-Based Instructional Reform in Mathematics Education

Integrating CT in school curricula appears to align with certain instructional reforms for mathematics education including integrating digital tools (Sinclair & Robutti, 2014) which is a key part of mathematics instruction reform. In tool-based reform old, as well as new, learning tools are being brought together to support learning. The educational tool — whether historical or contemporary, physical or digital — can be complex (Bartolini & Martignone, 2014) and still costly (Artigue, 2002) thus learning tools need to be approached as pedagogical instruments (Artigue, 2002) that have epistemological and curricular implication as they influence what is learned and how it is learned.

Integration of CT activities with mathematics thinking activities

Resnick (1998) envisions that introducing CT in schools involves both teaching a school subject through CT while teaching about CT. To integrate CT programming concepts and mathematics curricular concepts is to teach mathematics curricular through CT programming activities and at the same time teach CT programming concepts, and this is distinct from teaching CT programming concepts on their own. Gadanidis (2015) refers to integrating CT and mathematics as creating rich CT contexts for learning mathematics content. As well, CT programming curricular is enriched when it is taught with examples from specific subject areas that are common to learners and specific areas are enriched by using CT programming as a context (Sengupta, Kinnebrew, Basu, Biswas, & Clark, 2013).

RESEARCH DESIGN: MATERIALS AND METHODS

This research sought to further understand the integration of CT tools and activities in the teaching of mathematics in elementary schools. The researchers collaborated with teachers from four schools to co-design as well as co-teach activities in which CT was integrated in the teaching of mathematics to explore the plausible paths, the enablers as well the tensions of integrating CT activities (specifically, programming activities) with mathematics activities.

CT Programming Activities

The data reported in this paper is from sessions where students engaged on geometrical and measurement mathematics tasks, and utilised both mathematics content-specific and non-content-specific CT tools.

CT tools and Activities

Gadanidis, Hughes, Minniti and White (2017) adopt three major categories for tools that are appropriate for mathematics: screen-based coding, digital tangibles and off-screen coding tools. The researchers selected to utilise three categories of tools: Programming Languages which are screen-based tools, digital programmable materials some of which were tangibles and others were off-screen tools, and programming learning apps, games and simulations, some of which were content-specific.

Methodology

Study context:

A mixed strategy (Creswell, 2014) qualitative case study approach was utilised to construct stories of teaching and learning as bounded systems (Yin, 1994) with 74 students, from four grades 2-8 classrooms and their classroom teachers who consented to participate in the study. Table 1 summarises the contexts of the classrooms in which the study was carried out. Each school represented a bounded case as learning activities in a school were designed in collaboration with the classroom teacher to meet the teacher’s pedagogical goals.
Table 1. Classroom Contexts for the Project

<table>
<thead>
<tr>
<th>Grades</th>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grades 2 and 3</td>
<td>Grades 2 and 3 Inner city, Few Years of Teaching Experience, French Immersion school.</td>
</tr>
<tr>
<td>Grades 3 and 4</td>
<td>Urban, Several Years of Teaching Experience</td>
</tr>
<tr>
<td>Grades 7 and 8</td>
<td>Sub-urban, Several Years of Teaching Experience</td>
</tr>
<tr>
<td>Grades 8</td>
<td>Rural, Several Years of Teaching Experience</td>
</tr>
</tbody>
</table>

Task Design

The first research question was investigated through a collaborative process of designing the tasks. The researchers developed CT and mathematics activities based on the literature and in collaboration with classroom teachers. Two models were used: activity centres and mini-project activities. The nature of the activities varied in length and structure based on the grade level, classroom time allocated, and prior learning by students with CT tools. Most tools were not specific to mathematics, but the activities were designed with specific mathematics learning goals.

Methods of Analysis

To focus on the second research question, the researchers analysed data from teacher surveys, audio records of conversational interviews with teachers as well as photograph and photocopy data of students' work products and of teachers’ presentations. Teachers also provided input on the activity design, information about the classroom, and feedback on the draft activities. The researcher analysed how students engaged, what mathematics thinking they engaged on, and what students and teachers said about students’ engagement during the activities. All four case studies were investigated for moments referred to as "moments of choice" (Mason 1998), or critical moments, that caught the researchers’ attention, among the different cases.

Critical Moments

The data analysis presented here is centred on three critical moments which related to mathematics curricular and pedagogical goals enabled by the CT and Mathematics activities: participants working on mini CT and mathematics projects, participants reflecting on mathematics concepts embedded in the CT tools or enacted by the CT tools, and participants noticing parallels between CT and mathematics concepts and processes. The critical moments provided the basis for selecting data which was analysed. We do not elaborate on these critical moments here due to space limitations.

RESULTS

We report results on two CT and mathematics thinking activities that we saw to enable both CT and mathematical thinking among the critical moments studied: path and polygon drawing activities, and navigating maze and solving geometrical puzzle activities. In this section, we elaborate on these activities and examine the CT, mathematics, and CT and mathematics concepts explored in the activities.

Paths and Polygon Activities:

During exploration centre activities, students planned and programmed robots or screen characters to navigate a defined path, usually a shape that portrayed geometrical properties. For example, students took a robot around the room, or on a polygon path marked on the floor. They coded the robot (or, screen character) to move from a starting point to an end while making specific turns, covering distances and time lapses, moving at a specific speed,
navigating a perimeter, enclosing an area, or tracing a shape with geometrical properties. Students thus explored and analysed geometry properties and relationships of paths, shapes and polygons, as well as related linear measurements. Figure 1 shows the sample code that the students used.

![Sample codes for specific polygons and paths](image)

**Figure 1. Sample codes for specific polygons and paths**

In terms of CT concepts, assembling blocks to command characters and robots to move and turn, utilised movement blocks, direction blocks as well as their parameters, iterative (e.g., repeat loops) and conditional (e.g., if-then loop) logic. Students also explored concepts that appeared to be at the confluence of both CT and mathematics. For example, students visualised motion, simulated motion in the physical space with the robots and observed it animated by characters on screen. Table 2 summarises selected concepts that students encountered in the path and polygon drawing activities.

<table>
<thead>
<tr>
<th>CT Concepts</th>
<th>Math Concepts</th>
<th>CT and Math</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequencing procedures.</td>
<td>Geometrical properties of shapes.</td>
<td>Logic involved in coding motion.</td>
</tr>
<tr>
<td>Task commands.</td>
<td>Linear, area and time measurements.</td>
<td>Procedures for geometry.</td>
</tr>
<tr>
<td>Parameters.</td>
<td>Rates such as speed and percentages.</td>
<td>Logic of patterned shapes or motion.</td>
</tr>
<tr>
<td>Randomising.</td>
<td>Symmetry, patterns and repetition in movements.</td>
<td>Polygons as displacements of a point.</td>
</tr>
<tr>
<td>Logic.</td>
<td>Translations.</td>
<td></td>
</tr>
<tr>
<td>Control commands.</td>
<td>Grids and the coordinate system.</td>
<td></td>
</tr>
<tr>
<td>Debugging.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coding.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abstraction.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
As shown in Table 3, the coding of paths and polygons appeared to offer an opportunity for students to review concepts, learn concepts related to the curriculum for the specific grade, explore some concepts normally explored at later grades as well as encounter new and more abstract concepts.

**Table 3. Mathematics concepts explored in relation to the curriculum**

<table>
<thead>
<tr>
<th>Geometry and Measurement Curricula Concepts in the Path and Polygon Drawing Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Review:</strong> E.g., angle relationships in polygon</td>
</tr>
<tr>
<td><strong>Different:</strong> E.g., describing a polygon or a shape by movements and turns</td>
</tr>
<tr>
<td><strong>Advanced</strong> for the lower grades: E.g., Percentages</td>
</tr>
<tr>
<td><strong>New:</strong> E.g., Description of polygons in term of displacements and turns.</td>
</tr>
<tr>
<td><strong>Abstract:</strong> E.g., Using the concepts of logic.</td>
</tr>
</tbody>
</table>

Navigating Mazes and Solving Geometrical Puzzle activities:

Selected block-based programming tools are based on the maze and puzzle metaphor. In the maze activities, for example, learners engaged in activities based on locating objects, identifying paths to navigate and ultimately getting robots or characters to escape mazes.

As shown in Figure 2 and 3 of navigating a maze by a digital object, commands for navigating the mazes similarly involve geometry as well as related measurement concepts. Additionally, commanding certain robots involves input and event blocks (e.g., sensing an obstacle) and certain maze apps, as shown in Figure 2, prompt students to think about conditional logic (e.g., if-then-else loops) that they could use to automate patterned movements. Students had opportunities to simulate what they thought were the solutions and then get feedback from the simulations of new concepts.

![Figure 2](https://blockly-games.appspot.com/maze)

**Figure 2. An advanced level Blockly Puzzle solved by Grades 3 and 4 students. Source:** https://blockly-games.appspot.com/maze

The tensions noted in the study are reported together with their epistemological, curricular or pedagogical recommendations: The tension of different, new, advanced and abstract concepts requires that teachers need support to navigate probable epistemological tensions. As well, there is a considerable time investment when working on mini-projects that makes it important that specific learning and curricula goals are addressed in the activities. Students also appeared to transfer templates from learning and playing with similar technologies in non-structured settings. It was, thus, important that the pedagogy during the classroom activities provided structured, goal-oriented explorations to complement non-
structured explorations. Further, for the tensions that were presented by the design of the tools such as embedding abstract concepts, it was important that the abstract or different ideas involved were intuitive and that students could experiment with the tools to make observations that support understanding of these concepts.

![Figure 2. Two students program Sphero robots to navigate a maze](image)

**DISCUSSIONS**

In the study reported here, we analysed data from four elementary classrooms where students engaged in CT and mathematics thinking activities in the context of activity centres and mini-project. Two CT and geometry and measurement activities considered as enabling mathematics learning were presented: path and polygon drawing activities as well as navigating maze activities.

Exploring mathematics concepts using CT tools was present in Papert’s (1996) and associates work, as well in the work of scholars (e.g., Resnick, 1998) who researched teaching programming using CT tools, as well as scholars who harnessed and designed CT tools for learning mathematics content (e.g., Gadanidis et al., 2017; Noss, Healy, & Hoyles, 1997).

The finding that CT activities afforded students to explore mathematics concept embedded in the CT tools, some of which were advanced and abstract concepts, has been reported by Gadanidis (2015) and Sengupta et al., (2013). Our work contributes to the focus on the tasks that are designed to engage students in CT activities with subject-specific goals.

**CONCLUSIONS AND SIGNIFICANCE**

Elaborating on the CT, mathematics, and concepts that emerge at the confluence of CT and mathematics thinking evinces epistemological enablers in the activities presented in the results section. The study has implications for design of content-specific activities that utilise CT tools in classrooms, and it suggests that there is potential of integrating CT in mathematics activities. thinking, as well as for concepts that emerge at the confluence of CT and mathematics thinking are provided. The reflection on the conceptual, curriculum and pedagogical tensions evince that teachers who are currently integrating CT and mathematics thinking activities need support to navigate these tensions and that further design of activities and research on the implementation of these activities is needed.
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TEACHING CODING AND COMPUTATIONAL THINKING IN THE EARLY YEARS OF SCHOOL

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ABSTRACT
Recent Australian and State educational initiatives have introduced coding and computational thinking into the early years curriculum. Teachers are now faced with developing practices to support young children’s coding and computational thinking. Using an ethnographic case study methodology, and applied participatory action research model, this study will investigate the pedagogic practices of two teachers in Preparatory classrooms. Data collection methods include field notes, classroom video recording and teacher-researcher discussions. Conversation analysis and thematic analysis are to be employed in addressing the research questions: What does it mean to be an early childhood teacher of coding and computational thinking? What pedagogic practices does an early years’ teacher engage in to support students’ coding and computational thinking? This study will inform teacher pedagogical practices involving coding and computational thinking in the early years of school.

Keywords: Early childhood, teacher, technology, computational thinking, pedagogy, coding, preparatory, teacher practice, early years

INTRODUCTION
Coding and computational thinking are newly mandated curriculum areas in the Australian education system. Little is known, yet, about how teachers implement and teach coding and computational in the very early years of schooling. The purpose of this study is to explore teacher pedagogic practices incorporating coding and computational thinking in the early years, with an emphasis that the findings will support the everyday pedagogic practices of early years’ teachers.

Coding and computational thinking in upper primary and secondary educational classroom settings, as well as prior to school and after school coding clubs, is a well-researched area. A number of studies focus on secondary year students aged twelve and fourteen years (Burke, 2012), and on upper primary school students aged nine to eleven years (Kahn, Sendova, Sacristán, & Noss, 2011). Little is known, however, about computational thinking and coding in the lower primary classroom setting.

Several reasons have been posited for why little is known about what is happening in the early years. First, coding and computational thinking activities may not be happening in the early years of school (Bers, Seddighin, & Sullivan, 2013). Second, some suggest that early childhood teachers lack knowledge and understanding about technology, and about the developmentally appropriate pedagogical methods to apply coding and computational thinking in to the classroom (Bers et al., 2013). A third reason was found in a study by Thorpe and colleagues (Thorpe et al., 2015), which highlighted that early childhood teachers did have knowledge of digital technologies, but rather they had different beliefs about the
value of digital practices within a play-based program. Their concerns centred around appropriate implementation, and structural concerns such as having no Internet in the classroom. With fewer practices occurring in the early years, it is not surprising that research has not been invested in this area.

LITERATURE REVIEW

Coding and computational thinking is identified as being important to children’s lives and their futures. Even with coding and computational thinking being recognised as an important field internationally and within Australia, there are scarce opportunities for students to develop computational thinking skills and coding concepts between Preparatory (Prep) and Year 12 (Portelance, Strawhacker, & Bers, 2016).

Coding and Computational Thinking

Coding and computational thinking have received considerable attention over the past several years. There is little accord on a definition for computational thinking, however, the definition continues to be emergent (Chen et. al., 2017). The Australian Curriculum defines computational thinking as a “A problem-solving method that …. include(s) organising data logically, breaking down problems into parts, defining abstract concepts and designing and using algorithms, patterns and models” (Australian Curriculum and Reporting Authority [ACARA], 2017). Brennan and Resnick (2012) designed a computational thinking framework that comprises of three elements: (1) computational thinking concepts, (2) computational thinking practices, and (3) computational thinking perspectives.

Coding and Computational Thinking in the Early Years

Previous research within the early years has revealed that children as young as four (4) years of age can learn simple programming concepts. For example, Wilson and Moffat (2010) took Scratch®, a programming language that promotes creativity, coding and sharing (Resnick et al., 2009), and used it to deliver lessons introducing coding to novice users. The purpose of their study was to investigate: (a) if coding concepts are taught well using Scratch, and b) if the use of Scratch is fun for a younger age group. A driving force behind this study was the deficit in research pertaining to coding within classroom environments, and specifically, younger aged schoolchildren identified as coding novices (Wilson & Moffat, 2010).

Coding and Computational Thinking Teachers Practice

Currently little is known about the impact of technology, technological tools, coding and computational thinking on teachers’ practices. For example, a number of empirical studies on coding and computational thinking conducted within school settings between 2006 and 2016 indicated researchers rather than teachers predominantly facilitated the coding and/or computational thinking activities/lessons within the classroom. This finding is further substantiated by Strawhacker, Lee, and Bers (2017) who state “in many studies that examine children’s learning outcomes in technology-rich environments, the researchers themselves often develop the lesson plan and lead instruction” (2017, p. 3). This finding can be interpreted as an indicator that further research is required on, teachers’ perspectives on their practices, and professional development to implement coding, computational thinking, and technological tools into their classrooms.

Teachers often lack the skills and acumen to risk trialling and exploring with technology tools to enhance their educational impact (Lee, 2011). While some studies have pointed to the lack of skills and acumen, other studies have shown it is more complex than that. For instance, Thorpe et al. (2015) found teachers use technology a lot at home but may not necessarily use it in the classroom. This is primarily because of structural reasons, such as
no laptop in the classroom, or no to poor internet connection in the classroom. As well, teachers may have a philosophical belief that play is important and they cannot see how technology and play work together (Thorpe et al., 2015). In addition, training and professional development may help prepare teachers to integrate coding and computational thinking into their classrooms and lesson plans, as well as provide the resources to develop coding and computational thinking skills with their students.

**METHODOLOGY**

The participatory action research (PAR) model will be applied to provide insight into teachers’ pedagogical practice developing coding and computational thinking with students in the early years of school. Participatory action research is based on qualitative data that permits the views of groups to be involved (Kemmis, McTaggart, & Nixon, 2014); for example, in this study the teachers and researcher. During the PAR cycle the researcher and teachers will take on specific roles. The researcher takes on the role as researcher participant and the teachers take on the role as participants and collaborators. The study will investigate the following research questions.

1. What does it mean to be an early childhood teacher of coding and computational thinking?
2. What pedagogic practices does an early years’ teacher engage in to support students’ coding and computational thinking?

**Participants**

In addition to the researcher being a participant, two Queensland primary school preparatory teachers and their classes of approximately twenty-five students per class are to participate in this study, over a ten-week period. The selected site is a co-educational Primary School of approximately 500 students from Prep to Year 6 and located within the Brisbane metropolitan region.

**Figure 1. Action Research Model (Kemmis et al., 2014)**

**Participant Action Research Model Approach**

The study will follow the PAR model of planning, acting, observing, and reflecting (Kemmis et al., 2014). In using this approach, the study will explore and learn about the teaching pedagogies of a teacher developing coding and computational thinking within a Prep class. Although this model is a cyclic model, due to the scope of the study, only one participatory action research cycle will be conducted.

**Planning Stage – Researcher and Teacher Co-Planning**

The planning stage in the PAR model identifies and lists the steps to be taken to solve the problem or issue to be investigated. It is a participatory and collaborative process where
the stakeholders come together to discuss what they will do and how it will be done (Kemmis et al., 2014). The planning stage of the study consists of two phases. The first phase involves the researcher engaging in the classroom culture and observing the everyday classroom practices, as participation rights of children in research include children being well informed, having their views listened to and to be respected by adults. The second phase sees the researcher and teachers co-planning the learning experience during a school term on negotiated dates and times as to not inconvenience the school, the class and the teachers.

**Acting Stage - Teacher and Students participants in Learning Experience**

In the “Acting” stage, the agreed steps are taken (Kemmis et al., 2014). This stage will occur during a typical prep lesson session that has been predetermined in the planning stage. In this stage, the planning is systematically implemented. In the enactment of the plan, each prep teacher will deliver the learning experience to their prep class students. In this study, however, the acting stage is not a stand-alone stage, but is occurring at the same time as the observing stage of the PAR cycle.

**Observing Stage - Researcher as Observer**

Making observations requires examining what is happening and describing those happenings accurately. Therefore, including observational techniques in the research design the researcher is guided by what to observe based on aspects such as the theoretical framework, the problem or issue, and the research questions of the study (Stake, 2010). Moreover, when a researcher is conducting observations, it is essential to keep at the forefront the purpose for conducting the study (Stake, 2010). For example, observations are to be used in the analysis of a teachers’ pedagogical practices.

**Reflecting Stage – Researcher and Teacher Co-Reflecting**

The final stage of the iterative PAR model is the reflection stage. During this reflecting stage, data is reviewed, the findings are discussed, and it is decided whether the action has helped to solve the problem or the issue (Kemmis et al., 2014). This is also the stage where the teachers and researcher come together to reflect and discuss what has occurred in all the previous stages of the PAR model. Where reflections are based on the collected evidence, however, they may also be informed by literature (Kemmis et al., 2014). Since, PAR model is a cyclic model, stemming from the results of the reflecting stage, further planning occurs, to decide what needs to happen next, and the cycle begins again.

The component of the study reported here is qualitative in nature, drawing on an ethnographic case study approach. The main purpose is to gain insights into teacher practices of early year teachers on coding and computational thinking in the classroom. Such as, teachers’ initial knowledge, awareness, and appreciation of coding and computational thinking. This study will utilise field notes, video and audio recordings, discussions, and photographs of student work samples. Data will be obtained from the video recorded verbatim transcriptions of each class lesson involving student/teacher interaction and from students’ work. Video recording the learning experiences will provide data for the analysis of the social action and interaction of a classroom setting and provide an opportunity to acquire data on the teacher’s pedagogical practices.

**DATA ANALYSIS AND RESULTS (YET TO COME)**

The results of this study are to be illustrated as emerging themes and sub-themes of the corpus data. Therefore, the data analysis strategies of Conversation Analysis (Pomerantz & Fehr, 2011) and Thematic Analysis (Braun & Clarke, 2015) will be used on the corpus data to identify the main themes in the teacher/students’ interactions of the coding and computational learning experience.
Conversation Analysis

Conversation analysis as a research tool can investigate key interactional strategies, addressing the original research questions and providing an in-depth insight. The purpose of conversation analysis is to “explicate the shared methods interactants use to produce and recognise their own and other people’s conduct” (Pomerantz & Fehr, 2011, p. 69). The conversation analysis procedure incorporates a five-step procedure that will be used to extricate the study’s results and findings on teacher practices involving coding and computational thinking in the early years of school. Five steps include: (1) Select a Sequence (2) Characterise the actions in the sequence (3) Consider how the speakers’ package their actions (4) Consider how the timing and taking of turns provide for certain understandings of the actions, and (5) Consider how the ways the actions were accomplished implicates certain identities, roles, and/or relationships.

Thematic Analysis

Thematic analysis is a method of identifying, analysing, and reporting themes in a qualitative research study. Thematic analysis helps organise and describe the collected data in rich detail and also helps interprets different aspects of the research topic (Braun & Clarke, 2015). The purpose of thematic analysis is to identify themes and use these themes to address the research questions or say something about an issue. The thematic analysis incorporates six steps: (1) Becoming familiar with the data (2) Generating initial codes (3) Searching for themes (4) Reviewing the themes (5) Defining and refining each theme and (6) Writing up the analysis report. The framework steps are not linear, and offer flexibility during analysis and this procedure is to be used in extract the findings and results of this study.

DISCUSSION

There are three main emerging points regarding the teaching of coding and computational thinking in the early years of school. The first point is centred around policy direction in Australian education. The forward thinking of this policy direction on a national and state level has recognised the value of coding and computational thinking and they are embedded in the Digital Technologies curriculum. However, the policy direction has not appeared to have addressed the lack of knowledge and confidence of the teachers who will deliver this curriculum.

The second point identified is that most research has been done with older children in upper primary and secondary school. There has been limited research with younger children. Moreover, there is a question of how young children learn coding and computational thinking when they may not have the necessary literacy or numeracy skills, and how to introduce concepts of coding and computational thinking through play.

Finally, it is clearly evident that in much of the work that has been done the researchers delivered the lesson or learning experiences. This study brings an agentic approach to working with teachers in a cycle of collaborative planning, acting, observing, and reflecting activities.

CONCLUSION

The importance of this study lies in its contribution to teacher pedagogical practices involving coding and computational thinking within the early years of school. The data and findings of this study may be used to inform preservice teacher education programs, and professional development to facilitate teachers’ further understanding on coding and computational thinking and how a teachers’ pedagogical practices with technologies can influence the learning experiences of students in their classrooms. Furthermore, this study has
recognised gaps in research pertaining to coding and computational thinking in the early years and recommends further studies within this area and the investigation into age appropriate technologies that are specifically developed for the use in early childhood and primary school settings.

REFERENCE


ABSTRACT

Responding to the United Nations’ sustainable development goals our research explores the process of creating social justice mathematics problems. As a collaborative action research group of six members from five countries with varied cultural backgrounds, teaching experiences, and academic pathways we are learning to teach mathematics for social justice. Dialogue as method is used to examine experiences of creating problems through which students can interpret and transform the world with mathematics. Data include close to 15 hours of audio-recorded dialogue meetings and developed problems. Results indicate creating social justice mathematics problems involves a complex dance between mathematics and social justice across all education levels. Challenges lived include questioning the content of mathematics as well as our own expertise to draw upon local and global problem contexts, and recognising the need for dedicated time and supports. The study highlights the need for continued collaborative dialogue that not only gathers educators across disciplines but also includes students as co-creators of mathematics problems that could change their relationship with the world.

Keywords: Social justice mathematics education, critical mathematics education, creating problems, social issues, teacher education.

INTRODUCTION

In 2015 the United Nations (UN) and its member nations agreed on 17 Sustainable Development Goals (SDG) to ensure economic, social and environmental well-being for all people worldwide by 2030. The first SDG is to “end poverty in all its forms everywhere” (UN, 2018). Other goals work toward reduced inequalities, access to quality education, peace and climate change. Addressing these global issues and human rights will require innovative strategies, inter-disciplinary perspectives, critical thinking, and involvement of different stakeholders including students and teachers at all levels.

A promising pedagogical approach for sustainable development is teaching mathematics for social justice (Gutstein, 2012; Wager & Stinson, 2012). This approach involves teachers and students engaging mathematically to understand and respond to complex social issues such as the SDGs. Although research in this area is relatively new, there are examples of teaching math for social justice at the elementary and secondary school
levels (Peterson & Gutstein, 2013), with beginning teachers (Bartell, 2013), and adults (Frankenstein, 1987).

However, we know little of what is involved in learning to teach mathematics for social justice (Nicol, Bragg, Radzimski, He, & Yaro, 2017). Our research contributes to this growing field by analysing our own experiences as beginning social justice mathematics teacher educators, graduate students, and practicing teachers. As no curriculum for social justice mathematics exists, we ask: What is involved in creating a social justice mathematics problem?

LITERATURE REVIEW

More than 25 years ago Skovsmose (1994) in Denmark and Frankenstein (1987) in the United States argued the need for a critical mathematics education that “tries to criticise authentic, real-life applications of mathematics” (Skovsmose, 1994, p. 141). Decades later Gutstein (2012) extended Freire’s ideas of critical consciousness in literacy development to the field of mathematics education. For Gutstein this meant supporting students in learning to read (interpret) the world and learning to write (transform) the world with mathematics, and involved helping “students to learn mathematics as a vehicle for social change” (p. 300).

As an example, Gutstein (2012) offers a project developed with students on gentrification and displacement in the Chicago area. Here the mathematics of change was a key concept in studying changing demographics and the policies that supported such displacement. Following Freire’s (1970/2000) call for liberatory education located in generative themes of importance to students, Gutstein’s (2012) project had “students investigate the mathematics of home ownership, loans, mortgages, and development schemes” (p. 308) so that students could participate in and respond to the forced displacement or gentrification within their communities. Gutstein (2012) found students engaged and motivated, with opportunities to “examine their lived experiences, deepen their sociopolitical awareness, and learn mathematics” (p. 306). Students learned mathematics while learning to transform their world to make it better.

Yet we still know little about what is involved in learning to teach mathematics for social justice. For example, how do teachers select, adapt or extend appropriate problems for this area? Although there are growing resources for teaching mathematics that consider social justice issues, engaging students in a critical mathematics education that supports students in better understanding their own lives makes it challenging to implement problems created elsewhere, designed for other students in different lived contexts.

Our study contributes to this gap by examining our own experiences learning to teach mathematics for social justice focusing specifically on what is involved in creating a social justice mathematics problem.

Freire (1970/2000) argued for a problem-posing curriculum with generative themes drawing from the lived experiences of students themselves. Gutstein (2012) provides a framework that includes knowledges such as these for making sense of teaching mathematics for social justice. Community knowledge is “what people already know and bring to school with them” (p. 300). Critical knowledge is “knowledge about the socio-political conditions of one’s immediate and broader existence” (p. 301) and classical knowledge is the “formal, in-school abstract knowledge” (p. 302) often referred to as school mathematics.

We recognise the need to further problematise the relationships among these types of knowledges, but for now draw upon this framework to imagine and critique contexts for
mathematics problems connected to students’ lives, of societal relevance, and with potential opportunities for social action.

RESEARCH DESIGN

We are a group of participatory researchers keenly interested in learning to teach mathematics for social justice. We perform overlapping identities including masters graduate student – practicing teacher (AC), doctoral students – researchers – instructors (KY, VR, EA), and academic researchers – teacher educators (CN, LB).

Collectively our mathematics teaching experience spans educational levels from primary to secondary to higher education. Our cultural/country backgrounds are diverse and include: Australia, Canada, Taiwan, Ghana, New Zealand, and United States. As a team we have met regularly for the past 1.5 years to explore possibilities and challenges of teaching mathematics that brings together mathematics, community, culture and students. In this way we participate as collaborative action researchers “taking an attitude of inquiry” (Marshall & Reason, 2008, p. 61) to deepen our interpretation and understanding of teaching mathematics for social justice.

We draw upon dialogue (Freire, 1970/2000) as method for our collaborative action research. Dialogue in this sense is more than conversation. Dialogue involves critically “thinking together” (Wells, 2009), where our dialogues provided catalysts for challenging our assumptions, ideas and visions for social justice mathematics.

For this paper we draw upon 5 dialogue meetings focused on critical understanding of creating social justice mathematics problems, each meeting lasting between 2 and 3 hours. All meetings were audio recorded and included detailed note taking. Over the course of these dialogue meetings we shared articles, field notes, critical reflections, and responses to tasks we set for ourselves.

For example, in one meeting we challenged ourselves to use Gapminder (gapminder.org), an online interactive tool for visualising global statistics, to create a mathematics problem. The following meeting we shared our created problems and critical reflections on the process. This cycle continued for the course of our dialogue meetings, with each meeting moving us back to critique our experiences and forward to consider next steps.

For this paper we individually and collectively analysed our developed problems and our critical reflections on the process of creating these problems. We were specifically interested in attending to the characteristics of and processes involved in making a social justice mathematics problem, the questions we asked ourselves in deciding the appropriateness of a problem, and criteria used to decide its value.

RESULTS

Dancing with Mathematics and Social Justice across Grade Levels

Analysing the problems created and our dialogue on the process of creating them indicates we were able to develop a range of social justice mathematics problems, across grade levels and contexts. However, we found most of our dialogue and problems were developed for students at the upper primary, middle, and early secondary school mathematics levels. We reasoned that the mathematics content of number operations, functions and relations, and statistics at these levels was broad enough to be open to explore a range of social justice issues of possible interest to students. We therefore challenged ourselves to create problems for early/primary or upper/post secondary education levels.
One member (LB) created the “Toothbrush Task” for use at the K-2 level drawing upon Gapminder’s Dollar Street visual and interactive database. The task involves comparing global dental healthcare strategies (naturally-resourced, plastic/manual, and electric toothbrushes), to different income levels, to photos of smiles of real people and families from different income levels and countries. Australian students were invited to create categories with the data and represent their findings with bar graphs. The problem was designed to broaden students’ images of what could count as a toothbrush and develop appreciation for innovative dental care strategies specific to various contexts, many unfamiliar to these students.

The problem challenged possible assumptions about relationships between income and dental health across countries. As a group we considered this a strong problem as it drew upon students’ experience (community knowledge), engaged appropriate school mathematics (classical knowledge), as well as challenged assumptions and broaden young children’s thinking (critical knowledge).

Creating problems at the upper/post-secondary levels was equally challenging for us. For example, one member (VR) sought to develop a social justice problem through which university students could learn the definition and application of integral calculus. Income inequality expressed by the Gini coefficient (measuring the level of inequality in income distribution by country) was chosen as a possible rich context to challenge her international students’ assumptions of wealth distribution. However, searching for appropriate data for her students to examine was laborious and time intensive, and in the end proved not feasible. Changing the context from income inequality to electricity consumption led to locating suitable data, but still required extensive time to prepare and format the data.

This problem and our discussion of it, highlights our interest in balancing a meaningful social justice context with meaningful mathematics. Our dialogues indicate our interest in creating problems that moved students beyond solving a given applied problem by selecting and manipulating provided values found within a problem. We agreed that selecting the appropriate context for learning mathematics and social justice was key, otherwise the context “may neither deepen students’ understanding of mathematics or the chosen social issue” (VR). Thus, developing social justice mathematics problems generally involved negotiating tensions and raised questions about the interplay or complex dance of mathematics and social justice in creating problems across education levels.

**Questioning Statistics as Mathematics**

Analysis of our experiences creating social justice mathematics problems highlights our questions around whether a distinction exists between mathematics for social justice and statistics for social justice. We questioned the ways in which the statistics of social issues can motivate the mathematics we need to teach. In the context of elementary mathematics, for example, the Toothbrush Task involved beginning data analysis and interpretation, and could be extended to include explorations of global poverty and hunger. Building an understanding of what elementary statistics reveals about an issue requires a variety of mathematical topics within the elementary curriculum, including number sense, percentages, decimals, and fractions.

As noted by group members (LB and AC), statistics is considered a mathematics topic in the elementary grade curriculum. However, as stated by one member, “When we change the context to upper secondary and university mathematics, the distinction between mathematics and statistics becomes more pronounced and the utility of statistics to motivate mathematical concepts blurs” (VR). Those in our group with upper/post secondary teaching contexts (VR and EA) struggled with the question of how we might create social justice
mathematics problems that are not statistical in nature. For example, group member (EA) asked, “how can we maintain mathematical rigor and content relevance so that our [social justice] problems are not always reduced to data analysis?”

In response to EA’s question, VR created a problem on future world population using United Nations data. The problem involves students in modeling population growth with exponential and polynomial functions, exploring the implications on rate of change (the derivative), and analysing comparisons to the UN’s projected populations for years 2030, 2050, and 2100. We considered this problem a “good” problem due to its potential for rich dialogue on global issues as well as the possibility of mathematical inquiry beyond completion of the problem as worded. However, questions about the heavy use of statistics and data analysis for social justice mathematics problems permeated our discussions.

This issue is important as it challenges us to broaden our mathematical contexts for possible created problems. Our dialogues highlight the assumption of the embedded role of statistics as mathematics at the elementary and middle school levels, and the general challenge to create problems that draw upon a range of mathematical concepts across grade levels.

**Drawing upon Collective Knowledge and Experiences**

During our team’s dialogue, we questioned our own understanding of the socio-cultural and political or economic context of our students, and how this informed our social justice mathematics problems. For instance, a problem by EA “Renting or Owning a Home” drew upon background knowledge of students who are predominately from low-income families. This mathematics task is carefully situated within a context for which students could easily connect and discuss issues of social concerns, such as income levels through escalating house prices across North America.

The team questioned the different meanings of ‘context’ and how this shaped our understanding and creation of social justice embedded mathematics tasks. For example, the Toothbrush Task generated a great deal of discussion as we questioned the use of a twig or stick as a toothbrush (known as a chew stick) to be an indicator of extreme poverty. Some team members shared their experiences living in Africa and other cultural settings where the use of chew sticks is prevalent in middle-class families or homes, and thus may not necessarily indicate extreme poverty in all contexts.

While some resources such as the Gapminder is a powerful resource, issues were raised on the need for teachers to gain personal knowledge or connections with the context of the social issues found on websites. “Or better still,” offered one member “engage in critically examining such data” (KY).

We recognised the depth of understanding about the context needed to develop mathematically appropriate and personally meaningful problems for students. Our discussions included multiple remarks on our appreciation to learn from each other, to draw upon different cultural perspectives, learn from each other’s expertise and experiences, and collectively and critically share ideas for creating contexts of social justice mathematics problems. As one member stated “I’m finding that our collective knowledge about a social context and issue is leading to better understanding of the tasks we’ve each created” (KY).

**CONCLUSIONS**

Teaching mathematics for social justice to engage students, worldwide, in issues of inequality, climate change, peace and tolerance is one way to address the UN’s 17 sustainable development goals and target of 2030. However, selecting, creating and adapting
mathematics tasks are challenging for many beginning and experienced teachers (Clarke, Grevholm, & Millman, 2009), perhaps even more so in the context of social justice where educators may feel they lack necessary expertise in areas beyond school mathematics. Our research contributes to the growing literature on learning to teaching mathematics for social justice and what is involved in creating a social justice mathematics problem.

Our results indicate that creating social justice mathematics problems at all grade levels, particularly early/primary and upper/post secondary education levels requires negotiating Gutstein’s (2012) community, classical and critical knowledges. We found ourselves engaged in a complex dance between school mathematics, the experiences and interests of our intended students, and opportunities for action and change. For us this means being educators with what Freire (1998) calls “epistemological curiosity” (p. 37) being open to learning to read (interpret) and write (transform) the world with mathematics.

Creating social justice mathematics problems is time consuming. Locating appropriate data and information, researching possible social justice contexts, and learning more about our students all require time and commitment that may be unavailable for many educators. Although educators can access resources for social justice mathematics problems these only provide examples of what is possible, as many problems are designed for students in a particular context.

Ironically, we recognised that what makes a problem ‘good’ is its localness, which at the same time limits its portability to different contexts. Perhaps, as one team member, EA noted, we can address this issue by creating both internal and external problems. Internal problems, similar to Freire’s (1970/2000) generative themes, are deeply connected to students’ experiences and place. External problems, on the other hand, are those that might not directly impact students’ lives but working on them could lead students to a deeper understanding of more personal problems to be able to act justly.

As a collaborative action research group we continue to study our experiences learning to teach mathematics for social justice, and for this paper have focused specifically on our efforts to design social justice problems. Like Freire (1998) we believe, “there is no teaching without learning” (p. 29), and find as beginning social justice mathematics teachers we are as much students of teaching as we are teachers of each other and our students.

With this we suggest extending this collaboration to include our students in co-creating social justice mathematics problems, drawing upon a curiosity, “that is critical, bold, and adventurous” (Freire, 1998, p. 38).

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ADOPTING A MODELS AND MODELLING PERSPECTIVE TO RE-CONCEPTUALISE MATHEMATICS PRE-SERVICE TEACHER EDUCATION

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ABSTRACT

We are two secondary mathematics teacher-educators who are attempting to instil amongst our students the Mathematical knowledge, skills and beliefs in regard to both disciplinary and pedagogical knowledge needed for them to become effective secondary-school teachers. We find ourselves at a cross roads of curriculum design as a result of whole-of-course design decisions; we are choosing to reconceptualise the way in which we support our students to becoming secondary-school Mathematics teachers. This re-conceptualisation draws upon our own experiences and understandings of issues in mathematics education. In this paper, we firstly provide a reflective account of the position in which we find ourselves, including a summary of the history leading to this point and the potential the future holds. We then frame our practice by some key literature we have found useful, including policy that guides our practice as teacher-educators. From this we identify a mathematical modelling-based framework through which we first reflect upon past practice and then envisage, or anticipate, future practice that will integrate pre-service mathematics teachers’ development of disciplinary and pedagogical knowledge, skills and beliefs.

Keywords: Mathematics, mathematical modelling, pre-service teacher education.

INTRODUCTION

As teacher-educators, our practice has the potential to not only shape the learning of our own pre-service teacher students (PSTs), but significantly (re)shape the teaching and learning of Mathematics, and more broadly STEM, in school settings. For this reason, the knowledge, skills and beliefs that we model, teach and assess are important and should be congruent with those that are expected in school environments. In this paper we present our shared concept of the knowledge, skills and beliefs we hold to be important in Mathematics education and put forward a set of principles to guide our work in pre-service teacher education. This reflexive stance comes at a time of significant whole-of-course re-design. In the spirit of this conference, we are considering the integration of STEM-related teaching and learning across the real educational settings in which our pre-service teacher education students learn and work.

This paper firstly introduces the context in which we work, providing some detail of the program of study that we teach into and how it is undergoing change that has provided the catalyst for our re-conceptualisation of why, how and what we teach. We then briefly discuss the literature that has shaped our reconceptualisation, including a set of principles to guide not only our practice as teacher educators, but that we hope our students might adopt or adapt to be their own as they engage their own students in the learning of Mathematics in school classrooms. We then use these principles as a basis to reflect upon past practice and to
anticipate the future and the impact that our approach may have upon the learning of both our own pre-service teacher students and, ultimately, their students in school classrooms.

**CONTEXT**

In Australia, and reflecting the global discourse around STEM education and its importance, real world problem solving has gained prominence through various reports and policy statements, including the recent report titled Science, Technology, Engineering and Mathematics: Australia's future (Office of the Chief Scientist, 2014). In literature, Lesh and English (2005) have discussed the importance of adopting a models and modelling perspective, describing the models and modelling perspective to go beyond “getting from givens to goals when the path is not obvious”, instead involving non-trivial problems that “tend to involve a series of modeling cycles in which current ways of thinking are iteratively expressed, tested, and revised; and, each modeling cycle tends to involve somewhat different interpretations of givens, goals, and possible solution steps”. More recently, we have been reminded by Brown and Stillman (2017) of the modelling-as-life conception of mathematics. The importance of mathematical modelling is reflected in Australian school curricula. Within our jurisdiction, significant emphasis has been placed upon mathematical modelling in the senior-secondary school curriculum with the inclusion of an explicit mathematical modelling process that forms that basis of summative assessment. To enable the development in school students of such problem-solving abilities requires teachers who themselves have similar understandings of mathematics and mathematics education.

In this paper, we focus upon the substance and structure of our university’s undergraduate pathway for qualification as a secondary-school Mathematics teacher. Study in this pathway involves taking discipline units (i.e., the development of mathematical knowledge, skills and beliefs) as well as curriculum studies units (i.e., the development of mathematical pedagogy knowledge, skills and beliefs). The first author has taught into the curriculum studies units over the past eight years, and held a position of course leadership during the time of course re-design. Similarly, over the last decade the second author has taught into the discipline units, and more recently curriculum studies units, taken by our PSTs, and has also held faculty-level teaching and learning positions. It is based upon these past experiences that we are in a position to comment upon PSTs demonstrated mathematics discipline and pedagogical knowledge, skills and beliefs.

We write this paper at a time of re-design, as we transition from old to new course structures. Perhaps most significantly in terms of course change, the re-design has afforded the opportunity to re-consider not just the organisation but also the nature and content of the discipline units and, in turn, how the discipline and curriculum studies units can be designed to integrate and mutually support one-another. This has been made possible by the recent transfer of the second author from the mathematics school in our university into the education faculty which delivers the undergraduate education course. In the old course, nearly all discipline units were taught by staff from a mathematics school (including the second author); in many cases the PSTs attended classes alongside undergraduate Mathematicians, Scientists and Engineers. Whilst we recognise the value of undergraduate pre-service teachers studying alongside students enrolled in science, mathematics or engineering courses, we also assert that the pre-service teachers have a different set of needs and hence require discipline units that target these requirements. The importance or relevance of learning mathematics in secondary pre-service teacher education programs that extends significantly beyond that taught in schools has been debated in the literature. For example, Wasserman, Fukawa-Connelly, Villaneuva, Meija-Ramos, and Weber (2017) suggest that there is little evidence to
support that such advanced study “influences future teachers’ instruction” or “improves their students’ subsequent achievement” (p. 560) and that instead disciplinary learning should be situated in the work of the teacher. In our new course design, the majority of discipline units will be designed for and exclusively taught to PSTs, such that their discipline knowledge is developed in the context of becoming a mathematics teacher. The afore-mentioned changes, in particular the shift to PST-specific discipline units, has provided the catalyst for us to re-conceptualise our approach to pre-service mathematics teacher education.

SHAPING OUR RE-CONCEPTUALISATION

Various bodies of literature have informed our reflection and re-conceptualisation of mathematics pre-service teacher education. This has included literature regarding the knowledge and skills needed for mathematics teaching in school environments, the relationship between teacher beliefs and practices, ways in which pre-service teachers’ professional learning can be supported, and the pedagogies that can be used to support students learning of mathematics that align to the intended outcomes of school-based mathematics education.

The knowledge needed for the teaching of Mathematics has been theorised by various authors, including the seminal work of Shulman (1986) who promoted the focus upon teachers’ pedagogical content knowledge. This has been extended, including the proposition of Mathematical Knowledge for Teaching (MKT) by Ball, Thames, and Phelps (2008) and the refinement of Shulman’s original ideas to incorporate topic-specific professional knowledge that is used by teachers to translate their mathematical content knowledge into teaching and learning activity (Gess-Newsome, 2015). Common to these various models is the general relationship of teachers’ mathematical knowledge and skill informing their development and application of pedagogical knowledge and skills, which in turn shapes their classroom practices and ultimately the learning of their own students. Whilst that linearity is queried in literature (e.g., Clarke & Hollingsworth, 2002), it does provide a starting point for us to consider the relationship between our students’ learning of mathematics subject matter and mathematics pedagogy, as they prepare for and reflect upon their professional experience.

Whilst we recognise the importance of fostering positive affective beliefs, our focus in this paper is upon the development of epistemological and pedagogical beliefs towards mathematics. This focus drives the way in which we are designing undergraduate study that supports the development of PSTs whose beliefs are aligned to the school curriculum that they will one day be responsible for teaching. In doing this, we recognise the influential role that prior learning of mathematics, both in school and university settings, has upon beginning teachers’ pedagogical practice. Beswick (2012) has proposed a two-dimensional matrix that identifies continua of teacher beliefs in regard to mathematics (epistemological) and mathematics education (pedagogical). The continua in each dimension identify similar categories of Instrumental, Platonist and Problem Solving. Beswick’s matrix provides a lens through which to consider the beliefs modelled (and the intentions of learning) in both discipline and curriculum studies units. When compared to the intentions of the constructivist-oriented school curricula for which our students are being prepared to teach, our approach to course design needs to foster a problem-solving oriented belief to both mathematics and mathematics education.

Considering these key ideas regarding content and pedagogical knowledge, skills and beliefs has allowed us to synthesise a simple model to guide our practice as teacher educators. This model, which identifies the bi-directional links between teacher discipline and
pedagogical knowledge, skills and beliefs, classroom practice, and (ultimately) school students’ discipline knowledge, skills and beliefs, is summarised in Figure. Whilst uncomplicated this model provides an anchor for us to consider the ways in which our teaching, and our PSTs learning, is inter-connected across the discipline and curriculum studies units and, ultimately, our students in-school teaching.

![Figure 1. Model of bi-directional relationships between PST and school student knowledge, skills and beliefs](image)

Returning to the idea of the models and modelling perspective of mathematics education, we are drawn to the model-eliciting work of Lesh and colleagues (e.g., Lesh, Hoover, Hole, Kelly, & Post, 2000) who have suggested six principles that can be used to guide the development of model eliciting activities in mathematics classrooms. Central to the pedagogy of model-eliciting activities is the authentic mathematical work of constructing mathematical structures with which to represent or model phenomena (i.e., the process of mathematising). This idea of mathematical work resonates with us and we believe it aligns to the intentions of the mathematics curricula that we are preparing our PSTs to teach.

More recently, in a study of approaches to modelling-based teacher education, Sevinc and Lesh (2018) have suggested that these six principles could be used as an analysis framework for the ways in which mathematical modelling is incorporated into pre-service teacher education. Sevinc and Lesh (2018) based this claim upon their exploration of methods course-work for pre-service mathematics teachers that was design to embed the models and modelling perspective. Extending upon this claim, our intention is to use the six modelling principles suggested by Lesh et al. (2000) to guide our reflection upon, design, and delivery of learning in both the discipline and curriculum studies units.

**REFLECTION ON PAST PRACTICE**

We have chosen to adopt the set of principles suggested by Lesh et al. (2000) as a basis for reflecting upon our past experience in discipline and curriculum studies units, and then anticipating the future as we re-design the substance and structure of both the discipline and curriculum studies units to mutually re-inforce one-another. Accompanying the descriptions of the six principles, Lesh et al. (2000) also posed associated questions that can be used to test whether the principle has been satisfied. In the following, we use the guiding questions for each principle as a prompt to reflect upon our teaching and our students’ learning in both discipline and curriculum studies units. This reflection is a distillation of conversations we have had, in which we have shared and critically discussed our respective teaching experiences. From this, we then make tentative inferences regarding the apparent beliefs, both epistemological and pedagogical, that our students tend to demonstrate.
The Reality Principle - Could this really happen in a real life situation?

Our experience is that discipline units tend to over-simplify the real-world; problems for students to solve are selected and presented in a way so as to clearly focus on the content that has been taught. However, real-world problems are never that straightforward. The use of such ‘sanitised’ problems reinforces a mathematics-as-computation disciplinary belief and limits the opportunity for mathematising to occur. The implication we have observed for curriculum studies units is that students often lack the experience and confidence to identify and leverage the mathematics in real-world situations, and tend to adopt pedagogical approaches that rely on explicit teacher modelling of mathematical activity, rather than a more problem-based approach to learning.

The Model Construction Principle - Does the activity include the development of an explicit construction, description, explanation, or justified prediction?

In a university-level undergraduate Mathematics course, it is usually only in the most advanced units (if at all) that students are engaged in true construction of models and their use for prediction and explanation. In our old course structure, our students never took these units. Instead, and because of the pre-requisite requirements and the limits of time, in our old course our students took lower-level units in which the need for students to construct models is often pre-empted by the use of problems that clearly identify the mathematical constructs to be applied. Just as the sanitisation of problems contradicts the reality principle, it also contradicts the model construction principle. Similarly, we assert that this results in (or consolidates) teacher-centric, behaviourist beliefs regarding the teaching and learning of Mathematics.

The Self-assessment Principle - Does the problem statement strongly suggest appropriate criteria for assessing the usefulness of alternative solutions?

The use of narrowly focussed questions in discipline units and the emphasis placed upon computational technique rather than modelling excludes the need for solution evaluation as there is only one anticipated solution. In turn, in curriculum studies units students often display a lack of confidence to search for alternate solutions. This stems from a lack of mathematising the problem and the identification of appropriate success criteria; rather than evaluating a solution with regard to the features of the problem, students are accustomed to evaluating their solution to the ‘model’ solution that was anticipated.

The Documentation Principle - Will responding to the question require students to reveal explicitly how they are thinking about the situation by revealing the givens, goals, and possible solution paths that they took into account?

In discipline units, the common expectation understood by students is to clearly document their calculations. However, the use of overly simplified problems that require little mathematising and for which the procedure and hence solution is more-or-less known in advance, means that there is little need to document and justify the full cycle of mathematical activity. Making explicit all aspects of mathematical thinking is an important pedagogical skill, especially when explaining or demonstrating a mathematical activity to students. The lack of experience of fully documenting a cycle of mathematical activity impinges upon students to clearly explicate their thinking.
The Construct Share-ability and Reusability Principle - Is the model that is developed useful only to the person who developed it and applicable only to the particular situation presented in the problem, or does it provide a way of thinking that is shareable, transportable, easily modifiable, and reusable?

Whilst in discipline units the importance of generalising is often discussed, in reality the strong content-coverage orientation results in limited opportunities to explore the content in a variety of contexts, and hence limited opportunities to form such generalisations. Often, curriculum units face the same challenges of covering a wide range of mathematical content to expose students to content-specific pedagogy, without providing sufficient opportunities for students to experience and realise the relationships, both mathematical and pedagogical, between various mathematical topics.

The Effective Prototype Principle - Does the solution provide a useful prototype, or metaphor, for interpreting other situations?

The discipline units in our old course are designed and taught in relative isolation to one another, by a broad range of often-changing academics. Consequently, it is difficult to provide opportunities for students to recognise and make-use of prior problem-solving activities as prototypes. Similarly, in curriculum studies units relatively short intervals of time are spent on the various topics in the curriculum that students are expected to be able to teach. Consequently, there are limited opportunities for students to experience and realise the importance of prior learning in the process of making sense of new problem situations.

Reflection upon the six principles suggested by Lesh et al. (2000) has led us to realise that whilst many of our students have sound mathematical knowledge and computational skills, they hold a relatively naïve understanding of problem solving and mathematical modelling; they believe problem solving to be important but see the problem as a ‘wrapper’ for the mathematics, rather than a purpose. This stems from the discipline units’ lack of emphasis upon authentic modelling activity, such as model construction and refinement, the interpretation of results, and the power of mathematical models as re-usable prototypes. When we compare our observations and reflections to the matrix proposed by Beswick (2012) it is clear that many of our students lack problem solving beliefs regarding mathematics, both in terms of epistemology and pedagogy. Rather, they hold instrumentalist beliefs and could be epistemologically characterised as a focus on skill mastery and pedagogically characterised as focussed on content and performance.

IN CONCLUSION: OUR ANTICIPATED PRACTICE

It is clear that we need to carefully consider how we can design our discipline and curriculum studies units to challenge our students’ epistemological and pedagogical beliefs. Whilst our students may have experienced a style of problem solving in their school education that Lesh and English (2005) would describe as “getting from givens to goals”, that approach is no longer adequate to meet the challenges of modern society and work, as reflected in new school curricula. So, our discipline units need to provoke and support the development of a problem-solving belief towards the teaching of Mathematics, what Beswick (2012) would describe as “helping students to appreciate mathematics as a powerful and creative process” (p.133). To achieve this, adoption of Lesh et al.’s (2000) six model-eliciting principles will guide us to design learning activities that are messier and require multiple cycles of mathematical activity that involve mathematising the problem situation to construct a model, the manipulation of the model to generate a solution, interpreting that solution in the original problem context, and critically reflecting upon the cycle of work. These principles will guide not only the learning of mathematics in discipline units, but also the construction
of learning activities in curriculum studies units that allow students to critically engage in mathematical activity and to unpack those activities in regard to their pedagogical features.

Our intentions are driven by the end goal of creating practices in school classrooms that develop school students’ understanding of mathematics as a creative, knowledge-building, problem-solving activity, as reflected in the school curricula. Adopting Lesh et al.’s (2000) modelling principles, and aiming to develop problem-solving beliefs in regard to both mathematical epistemology and pedagogy, we are positioned to create a community of pre-service teachers who will develop the knowledge, skills and beliefs needed to successfully teach in the own school classrooms and achieve the intentions of the school curriculum.

REFERENCES


QUEERING VIRTUAL REALITY: A PRELIMINARY DESIGN STUDY

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ABSTRACT

In this paper, we investigate how innovations in STEM, such as virtual reality (VR) and 3D Sculpting, can support the development of critical literacies about gender and sexuality. Our work arises from the concern that the assumed “naturalness” of male/female binary categories in biology is often at the center of the queer, trans, and intersex panics in public education. Echoing critical scholars and sociologists, we posit that transgender and queer identities should be positioned as realms of playful, active inquiry. Further, we investigate how new forms of computational representational infrastructures can be leveraged to design immersive and embodied learning environments that can support such productive and playful experiences of inquiry about gender and sexuality. We present a study in which a small group of friends in their early thirties with gender nonconforming and queer identities and life histories interacted in VR-based environments, where they engaged in two different forms of constructionist learning experiences: creating 3D sculptures of personally meaningful objects, and re-creating their VR avatars in VR social media. Our analysis illustrates how advances in STEM virtual reality based learning environments can be designed to support such experiences, and furthermore, how such experiences can be productively analysed using social constructivist perspectives that situate knowing as boundary play and figured worlds (Holland, Lachicotte, Skinner, & Cain, 1998; Sengupta & Shanahan, 2017).

Keywords: Virtual reality, gender, sexuality, queer, transgender, body-becoming, embodied learning, figured worlds

INTRODUCTION

In this paper, we investigate how innovations in STEM, such as virtual reality (VR) and 3D Sculpting, can support the development of critical literacies about gender and sexuality. Our work is motivated by the concern that the assumed “naturalness” of male/female binary categories in biology (Bazzul & Sykes, 2011; Westbrook & Schilt, 2014) is often at the center of the queer, trans, and intersex panics in public education and sex-segregated spaces, such as bathroom panics to legislate and culturally police trans people’s access to sex-segregated bathrooms (Cavanagh, 2010), medical panics that create “emergencies” around assigning a binary sex to intersex people (Davis, 2015; Davis & Murphy, 2013), and the panic in sports over whether and in which gender category intersex or trans athletes can compete (Karkazis, Jordan-Young, Davis, Camporesi, 2012; Travers, 2017). To address this
issue, echoing Thorne’s (1993) call for re-considering gender as social action and not merely as a category, Grace (2015) argued that we need to reconsider transgender and queer identities as “a realm of active inquiry, play and creative expression” (p. 49). This paper investigates how new forms of computational representational infrastructures – e.g., VR and 3D Sculpting in VR – can be leveraged to design immersive and embodied learning environments that can support such productive and playful experiences of inquiry about gender and sexuality.

While informal gender play and conversations with friends play important roles in the development of our gender and sexual identities (Thorne, 1993; Risman & Banerjee, 2013), there is little understanding of how such playful experiences with friends can be leveraged to support the development of a more socially just epistemology of queerness and transgender identities.

We present a study in which a small group of friends in their early thirties with gender nonconforming and queer identities and life histories interacted in VR-based environments. Participants engaged in two different forms of constructionist learning experiences: creating 3D sculptures of personally meaningful objects, and re-creating their VR avatars in VR social media.

Our analysis illustrates how advances in STEM virtual reality based learning environments can be designed to support such experiences, and furthermore, how such experiences can be productively analysed using social constructivist perspectives that situate knowing as boundary play and figured worlds (Holland et al., 1998; Sengupta & Shanahan, 2017).

THEORETICAL BACKGROUND

Virtual Reality, Playfulness and Friendships

Our work leverages VR, playfulness and friendships as anchoring experiences for fostering a deep engagement with complex conversations about gender and sexuality. Learning scientists have shown that embodied interactions and projections in virtual worlds – the fundamental form of experience in VR environments – can help people take on perspectives that would be otherwise difficult for them to adopt, in complex topics ranging from physics and chemistry to understanding racism and ageism (Abrahamson & Lindgren, 2014; Hostetler, Sengupta & Hollett, 2018; Oh, Bailenson, Weisz, & Zaki, 2016; Peck, Seinfeld, Aglioti, & Slater, 2013).

Learning scientists have also shown that playful learning environments can greatly facilitate learning of complex topics across a range of disciplines (Berland & Lee, 2011; Kim & Ho, 2018; Sengupta & Shanahan, 2017). Furthermore, studies also show that although dynamics within friendships may sometimes present challenges for learning (Mitchell, Reilly, Bramwell, Solnosky, & Lilly, 2004; Esmonde, Brodie, Dookie & Takeuchi, 2009), Takeuchi (2015) found that group work with friends can also offer greater opportunities for access to a wider variety of complex, disciplinary work practices and positional identities, for example, by enabling students to take on roles of both experts and learners.

Furthermore, sociologists have also shown that informal interactions and conversations with friends play a formative role for the development of gender and sexual identities for children and youth in the form of informal gender play (Thorne, 1993) and informal discourse about gender, sex and sexuality (Risman & Banerjee, 2013).
**Body-Becoming, Heterosexual Matrix and Figured Worlds of Queerness**

We draw from queer theory and Judith Butler’s (2006) notion of the *heterosexual matrix* as well as from Lane’s (2009) call for trans and queer studies to engage with a fundamentally more complex, *new materialist* biology and the concept of the *body-becoming*. The heterosexual matrix highlights the social system of constraints shaping understandings of gender and sexuality, where bodies are expected “to cohere and make sense” by expressing a stable, binary sex and gender through compulsory heterosexuality (Butler, 2006, p. 208). Lane (2009) critiques the discursive approach to the body, and argues that “feminist analysis needs to move from ideas of the body as constraining, fixed, and given toward ideas of the ‘body becoming’ as dynamic, transformative process” (p. 141). In this perspective, the body is both the place where gender is experienced, as well as a dynamic and expressive representation of one’s gender and sexual identities.

The analytic framework we use is grounded in the literature on *figured worlds* (Holland et al., 1998). Figured worlds are “sociohistoric, contrived interpretations or imaginations that mediate behaviour and so, from the perspective of heuristic development, inform participants’ outlooks. The ability to sense (see, hear, touch, taste, feel) the figured world becomes embodied over time, through continual participation” (Holland et al., 1998, pp. 52-53).

Holland et al. (1998) explained that “materially, figured worlds are manifest in people’s activities and practices” (p. 60) and queer and trans theory shows how the embodiment of figured worlds is also a matter of how figured worlds materially manifest upon people’s bodies. Finally, our work also builds on Sengupta and Shanahan (2017), who showed that boundary play in computational worlds that allow learners to project themselves as actors within the system being simulated involves the use of pivots.

Pivots are artifacts, culturally defined, that shift the frame of an activity and evoke or “‘open up’ figured worlds” (Holland et al., 1998, p. 61). The elements of a figured world – its artifacts, storylines, characters and their concerns, and the activities – help in positioning oneself meaningfully in relation to the figured world and can also serve as pivots. We posit that the heterosexual matrix, can be interpreted as a figured world, because it comes to be inscribed on the body and embodied as part of one’s identity, through everyday participation in reproducing the figured world. As will become evident in our analysis in the following sections, boundary play in VR involves the creation and use of pivots in the form of 3D sculptures, reflections, and conversations which can help us engage in both personally meaningful and socially disruptive discourse about cis-heteronormativity.

**METHODOLOGY**

We report a self-study conducted by a small group of four friends in their early thirties who are also part of a design team focused on designing VR applications for LGBTQI youth. The two participants, highlighted in this paper - Riley and Newman – consider themselves to be close friends with each other, as well as the first author, who was also a participant observer in the study. They also have gender nonconforming and queer identities and life histories. The setting was a room in a Western Canadian public institution for informal science education.

The first activity involved VR sculpting using the Oculus Medium VR sculpting application and Oculus Rift headsets. The second activity involved “playing” in Facebook Spaces, a social VR space that includes forms of virtual identity creation and sharing (e.g., avatar creation and VR “selfies”). In both these activities, we requested all the participants to go beyond simply using normative labels of gender and sexuality, and instead think about and
discuss with their friends their own experiences of gender and sexuality, with a particular emphasis on their experiences that they felt were meaningful for their own coming into their gender and sexual identities.

The observed conversations and interactions were audio and video recorded by the group. Recordings were transcribed and analysed through an interpretive lens informed by constant comparative method (Glaser, 1965). The focus of the analysis was on interpretively identifying the relationships between participants’ creative representations of gender and sexuality in VR, their conversations with their friends regarding gender and sexuality, and their own gender and sexual life-histories and identities. We used theoretical sampling (Glaser & Strauss, 2017) to iteratively identify segments from the transcribed data that would make explicit how pivots and figured worlds were becoming evident in the participants’ work.

Our analysis can also be considered to be phenomenographic in nature, based on Marton’s (1981) argument that phenomenography deals with the forms of immediate experience as well as conceptual thought and physical behavior. This is particularly important for our theoretical focus on figured worlds and boundary work, which involves not only how we act in the world, but also how we conceptualise and interpret our actions and the environment where we are and might be situated.

The figured worlds of the participants are also emergent and dynamically constructed through their interactions with creative work in VR and with each other. Our analysis, presented in the form of illustrative cases, shows how participants’ figured worlds of gender and queerness emerge through the creation and use of pivots (Finding 1), and how engaging playfully with friends in VR enabled them to talk about their experiences of hurt pertaining to gender and queerness (Finding 2).

FINDINGS

Finding 1: Pivots and Figured Worlds of Gender and Sexuality

When prompted to create an object in VR that represented a personally meaningful aspect of their gender and/or sexual identities, Sol, a professional VR artist and sculptor, initially sculpted a three dimensional “gender key”. She explained her work as follows (Fig.1):

*Fig. 1. Excerpt of Riley’s explanation of her sculpting process.*

In this excerpt, Riley explains that, for her, sculpting and imagining are deeply intertwined, in a manner that is analogous to Pickering’s description of scientific practice as a “mangle” - an inescapable intertwining of conceptual and representational work. Rather than first imagining what the sculpted object should be, Riley started with a key because that is what came to her mind.
Rendering shape to the initial sketch of the key, however, involved her remembering how she shaped her own body by piercing her one ear, in order to represent her queer identity when she was a teenager. Sculpting the key became a context for Riley to explore her figured world of gender and sexuality. The pierced ear was akin to a gender key - a key that would unlock the worlds of queerness for her by allowing her to belong to that world through re-making her body. The gender key thus became a pivot for Riley to launch into deeper reflections about her past. She further explained (Fig. 2):

Riley: So yeah, I only got one ear pierced and that was really unusual and I remember thinking at the time, ‘Oh, I don’t know which ear is the gay ear.’ But I wasn’t out yet. [...] And a lot of gay men used to use that, right? But I got one ear pierced. I believe it was my right ear and uh, I left it like that for two years and so that was a little, that was something that was, like, not quite correct for my gender, to only have one ear pierced, and so that was a memory that came up while I was sculpting that wasn’t something I was thinking about. I actually hadn’t thought about it at all until [...] I was already, like, a little bit queer compared to some of the, you know, girls in my school. I’d already been told I was too masculine by some of the boys.

**Fig. 2. Excerpt of Riley’s story about her gender and sexual expression as a teenager.**

Sculpting the gender key led Riley to remember a moment in her past when she had been reflecting on queer identity markers and ways of signalling queerness through re-making the body - an example of body-becoming (Lane, 2009), which emerged in Riley’s reflections as a central part of her figured world of gender and sexual identity.

She mentioned that her memory occurs prior to her coming out—meaning prior to publicly claiming a label outside of cisnormative or heteronormative expectations of cisgender or heterosexual identities. This suggests that her figured world of gender and sexuality was shaped through her own sense of incongruity with social expectations, as expressed by her peers who thought she was too masculine. She expresses her emerging awareness of incongruity with gender and sexual norms in terms of being “a little bit queer compared to some of the, you know, girls in my school” and being told she was “too masculine by some of the boys”.

Her story thus highlights a significant experience of body-becoming - i.e., her experience of inscribing gender and sexuality upon her own body - and it also presents a complex and nuanced image of her figured worlds of gender and sexuality as a teenager. Her figured world was at once improvisational and rooted in her implicit desire to be recognised as queer, while at the same time being grounded in her own interpretation of the heterosexual matrix.

**Finding 2: Sculpting “Hurt” Playfully: Journeys in Virtual Body-Becoming**

For Riley and Newman, gender and sexuality were shaped through their experiences of exclusion and incongruity in an existing cisfetnormative context among peers. As they proceeded further, their sculptures began to embody their experienced incongruities more viscerally and explicitly in the form of hurt.

Interestingly, despite the gravity of the stories and emotions represented in their sculptures, play was an important element of this experience. In this section, we describe the final versions of the sculptures, and explain how the sense of playful exploration can create a context for virtual explorations in body-becoming, which in turn can facilitate deep explorations of issues pertaining to gender and sexual identities.
When Newman and Riley returned to the Oculus Medium application and finished their sculptures after playing in Facebook Spaces, their sculptures looked very different from what they had completed earlier. Newman continued with his sculpture of hangers and clothing, but now he used stamps from within the application of gendered male body parts (an arm and a torso) and hung these from the hangers instead of clothing (Fig. 3).

![Image](image.png)

**Fig. 3. Newman’s part of the sculpture showing a dress, two arms and a torso (gendered male) hanging from hangers**

Newman explains why his sculpture took this turn from clothing to body parts as directly linked to the play experienced through the Facebook Spaces application (Fig. 4):

> Newman: In the play it was all about being able to try something new and different, uh, colouring on each other, creating jewelry out of nothing, that, "hey, this is cool! do-do-do-do-do. Hey, look, I put it on my ear! Little bits of creativity like that to almost exercise and get the mind going. Especially in that area of body exploration, which, as I say it, definitely, it brought forth ideas of my own body image and how it refers to gender, uh, and such. [...] Umm, in play it felt like I was being someone different, uh, being someone else, being playful, uh, being able to try different things as a different person. Here [in the second iteration of sculpting] was completely about how I perceived myself as I am, not really about what I want to be, or... something I want to try. So I guess in that sense, being able to play and experience the different sides of myself gave me more perspective as to how I view myself and who I think I really am. If that makes sense?

**Fig. 4. Excerpt of Newman’s explanation of his sculpting process**

Through play, Newman created a figured world where he could explore different sides of himself, playfully creating and playing with gendered objects that sparked thinking about body exploration. This became the context for virtual exploration of body-becoming. The gendered objects, like jewellery, became a pivot for Newman into the figured worlds of the gendered body.

When he returned to sculpting, Newman was able to reflect not only on how he challenged gendered, heteronormative ideas about clothing as a youth and his ongoing relationship with his body within the context of cisheteronormative society. Newman reflected upon his K-12 experiences of enforced masculinity and cisheteronormativity, for example, when he wore a dress to play a female character in a school play. Newman explained that wearing a dress was treated as a joke by his peers, even though he experienced it as a form of playful gender expression – a form of body-becoming.
Upon returning to sculpting, Riley’s sculpture also took a stronger turn towards the body and gendered assumptions. Riley sculpted a mannequin torso and head with mixed gendered characteristics (Fig. 5).

![Fig. 5. Riley's part of the sculpture showing a pierced ear on the side of a window frame with curtains and a mannequin torso](image)

On one side of the mannequin, she sculpted short hair and long eyelashes, and on the other side she sculpted the reverse and added a beard. On the torso she painted two checkboxes with the letter F, representing female, and the letter M, representing male. Stakes were driven through each box and into the torso. Riley explained that the sculpture represents how “if you express a mix of masculine and feminine characteristics, you are likely to experience double the injuries”.

**CONCLUSIONS AND DISCUSSION**

Overall, our analysis reveals how through creating boundary objects in the form of 3D sculptures and engaging in deep conversations with friends, Riley and Newman were able to represent and voice how gender and sexuality comes to be inscribed upon the body both through their own improvisational, playful acts of body-becoming and through the violence of cisheteronormativity imposed upon them. Play and intimacy were key elements of the participants’ experiences.

Gender-becoming is also body-becoming, and this was also true in VR. Riley’s initial sculpture (a pierced ear) represented her own experience and desire to express her gender and sexuality through body modification, a playful act of body-becoming through re-making her body. This improvisation in re-making her body demonstrates an exploration of her own figured world of gender as dynamic and playful, in the process, sharing a story that she had never shared before with anyone besides her partner. Play and intimacy also created an environment that made the participants comfortable enough to share their hurt around their gender and sexual identities. For example, both of their final sculptures contained expressions of gendered violence inflicted upon bodies that do not conform to societal expectations of gender and sexuality.

Although the work presented here is preliminary, we believe that it contributes to the literature in the following manner. Sociologists have reported that informal conversations and learning about sex, gender, and sexuality play an important role in shaping our gender and sexual identities (Thorne, 1993; Risman & Banerjee, 2013); however, these studies also highlight how heteronormativity is reinforced through these informal conversations and interactions. Our study, in contrast, provides an illustrative example where innovations in STEM – for example, VR and 3D Sculpting - can be used to create a positive space for engaging in conversations and computational creative work about queer and trans identities by leveraging informality and intimacy between close friends.
REFERENCES


A STEM METHODS COURSE FOR THAI PRESERVICE TEACHERS

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ABSTRACT

STEM education is being promoted in Thailand, but very few preservice teacher preparation programs include STEM options. This study presents the development of a STEM methods course design model. There are three phases in this model: the review of STEM literature and conceptual considerations, the planning of the STEM methods course, and the evaluation and revision of the course. The fifteen weeks of the STEM methods course is planned to model good practice about how to teach integrated STEM education by promoting the preservice teachers to engage in authentic issues and problems as STEM activities. The framework and guiding principles for STEM education in primary level showcase the key elements including student centred, real world issues and problems, authentic learning contexts and assessment. The preservice teachers who will participate in this methods course are expected to understand the concept of STEM integration and develop pedagogical content knowledge for designing and teaching integrated STEM lessons.

Keywords: STEM methods course, STEM education, primary level, preservice teacher

INTRODUCTION

STEM education is mentioned as a goal of education for many countries as a way to prepare citizens for life and to be part of the STEM workforce (National Research Council [NRC], 2011; Prinsley & Johnston, 2015; The Institute for the Promotion of Teaching Science and Technology [IPST], 2017). In Thailand, the government is endorsing STEM education at all educational levels. As in other countries, Thailand faces a decreasing number of students in science programs both in schools and universities. Thailand has low scores in international science and mathematics testing, has an inadequate STEM workforce and low world Competitiveness Ranking (ranked by IMD world competitiveness centre, Chulavatnatol, 2013).

There are many projects focused on STEM education such as those which support the National STEM Education Centre and Regional STEM Education Centres in schools and universities around the country, which act as teacher development centres. IPST is responsible for these projects (IPST, 2017).

Although STEM education is encouraged in many ways, the teacher preparation programs are not focused on this area. In the first author’s university, STEM education is not emphasised in the preservice teacher program but is just one topic in some courses. The preservice teachers have no opportunity to study, design lessons or practice to teach STEM. Moreover, the result from the preliminary study showed that most preservice teachers had an inadequate understanding in the concept of integration and how to teach STEM.

Although most preservice teachers were aware of the government promotion of STEM education, they could not coherently articulate the educational goals related to STEM.
education (Pimthong & Williams, in press). The need for effective preservice STEM preparation programs is clear in order to prepare quality future STEM teachers.

The objectives of this paper is to detail the development of a STEM methods course for the primary preservice teachers in Faculty of Education in a university in Thailand.

THEORITICAL FRAMEWORK

Concept of STEM and STEM education

STEM is the integration of science, technology, engineering and mathematics. Radloff & Guzey (2016) explained that STEM from the view of educators could be defined as a set of integrated or interconnected disciplines. However, STEM could also be defined in other ways which depend on the stakeholders or context in which it is viewed or conceptualised.

STEM education is important to prepare people to live in this time of change. Because of the nature of the world, each discipline does not exist alone; there are complex and multidimensional problems every day (Talley, 2016; Vasquez, Sneider, & Comer, 2013). STEM education should achieve the desired educational aims, be accessible by all, and address the core content and processes of the respective disciplines (English, 2017). Vasquez et al. (2013) presented STEM’s guiding principles as an emphasis on integration, related to everyday life, emphasising 21st century skills and challenging students to learn.

Similarly, Bybee (2013) stated that students should have opportunities to learn how to apply knowledge and skills to multidisciplinary situations one confronts in life. Moreover, “STEM literacy for all” is an important idea for preparing all citizens to be STEM literate and competent to understand STEM related global issues, recognise scientific from nonscientific explanations, make reasonable arguments based on evidence, fulfil civic duties at the local, national, and global levels (Bybee, 2013) and face the challenges of a science and technology driven society (NRC, 2011).

STEM integration

STEM consists of four main disciplines which have different content and procedural knowledge, but are interrelated. Science develops the knowledge for explaining the natural world while mathematics provides tools for making and understanding patterns and relationships among quantities, numbers, and shapes. Technology and engineering emphasise a design process to innovatively meet humans needs or wants. Science and mathematics use tools or devices which may be developed by a technologist or an engineer, while technologists and engineers uses science and mathematics to design and develop their systems and products.

The integration of the four disciplines is designed to support daily life which requires multidisciplinary knowledge and skills. Vasquez et al. (2013) explained three types of integration, namely multidisciplinary, interdisciplinary and transdisciplinary. Similarly, Bybee (2013) described nine perspectives of integration in STEM education such as STEM combined with two or three disciplines and STEM as a transdisciplinary course and program.

Vasques et al. (2013) and Bybee (2013) share the notion that integration may begin with two or more disciplines, but that a transdisciplinary approach is the goal to strive for integrated STEM. Some research studies showed ambiguous results of STEM integration. For example, Stohlmann, Moore, McClelland, & Roehrig (2011) presented problems with the integration of STEM programs in schools. For example, there was no mathematics integrated explicitly into the curriculum and had insufficient amounts of explicitly integrated science and engineering.
An important awareness of STEM integration is the need to respect each discipline for its identity, but it is not just a matter of bringing four disciplines together (Sanders, 2009). Integration can occur if there is a focus on both core content knowledge and interdisciplinary processes (English, 2016; Urban & Falvo, 2016). Furthermore, there is an important disciplinary integrity in science, technology, engineering and mathematics, but some elements of the disciplines can be integrated. STEM Education cannot replace science, technology, engineering and mathematics instruction, but an integrative approach which promotes integration can be beneficial (Sanders, 2009).

**STEM preservice teacher preparation**

In school, especially at the primary level, young children are naturally ready to inquire, design, create something or solve problems (Lópezleiva, Roberts-Harris, & Von Toll, 2016). The STEM teacher could be a key person to implement STEM education into classrooms (Sias, Nadelson, Juth, & Seifert, 2017). Teachers need to prepare well-designed STEM activities which promote student-centred learning while integrating core disciplines based on real world contexts (English, 2016; Johnson, Peters-Burton, & Moore, 2016).

STEM teachers are expected to have STEM understanding and pedagogical knowledge to promote students’ important 21st century skills, STEM knowledge, and how STEM relates to daily life and careers. It is a big challenge for all teachers to move toward integrated approaches in STEM (Shernoff, Sinha, Bressler, & Ginsburg, 2017; Stohlmann et al., 2011).

Preservice teacher preparation programs are important. The preservice teachers should understand STEM content, integrated STEM, and pedagogical practices that support STEM integration (Radloff & Guzey, 2016; Shernoff et al., 2017). A STEM teacher preparation program would be different to other disciplines such as science because it represents the integration of disciplines. Preservice teachers need support to understand the concept of integrated STEM, as well as the identity of each discipline.

**METHODOLOGY**

The learning activities in this course are designed to facilitate preservice teachers construction of their own knowledge by working collaboratively with others and participating with experts (instructors or other experts) in practising STEM teaching, while these experts are role models of STEM teaching. In this design model, learning is considered to involve both individually constructed and socially constructed knowledge (Bell, 1993; Driver, Asoko, Leach, Mortimer, & Scott, 1994).

The STEM methods course design model consists of three phases. In the preparation phase, the goals and objectives of the methods course were developed by surveying information from the STEM literature and conducting a needs assessment of preservice teachers.

For the planning phase, the organisation of the course, the course syllabus and the detail of activities were developed. Finally, the evaluation and revision phase involve a critique from experts and revisions to the course (Ahn, Cho, & Lee, 2013; Oliva, 2009; Posner & Rudnitsky, 1994; Tyler, 1971). The STEM methods courses design model is showed in Figure 1.
RESULTS AND DISCUSSION

Framework and guiding principles for STEM education

To develop STEM education at the primary level in Thailand, it is important to promote the core concepts of integrated STEM. The knowledge and practices (including STEM skills) of STEM disciplines need to be clarified before teachers can develop integrative strategies. The guiding principles for STEM education in Thailand at the primary level are showed in Figure 2. All primary students are expected to be STEM literate and be prepared for the future or to work in a STEM career.

Figure 1. The STEM methods course design model
Guiding principles for STEM education in primary level

These guiding principles reflect the key elements for teaching STEM and suggests how STEM teachers should act to prepare their teaching.

<table>
<thead>
<tr>
<th><strong>Student Centred</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- learning activities are based on student interest, prior knowledge and experiences</td>
</tr>
<tr>
<td>- students are engaged in self-directed learning</td>
</tr>
<tr>
<td>- students participate in lesson planning and assessment processes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Real world issues and problems</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- engaging students in real life issues or problems which cannot be fully understood or solved by the independent approaches of each discipline</td>
</tr>
<tr>
<td>- encouraging the students to create their project by engaging in design and production processes</td>
</tr>
<tr>
<td>- promoting students’ roles as members of the community who take responsible for solving community’s problems</td>
</tr>
<tr>
<td>- developing STEM skills</td>
</tr>
<tr>
<td>- developing STEM literacy</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Curriculum</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- analysing standards based content knowledge, skills and processes in the appropriate grade level</td>
</tr>
<tr>
<td>- sharing ideas among teachers to plan the lessons together</td>
</tr>
<tr>
<td>- preparing active and hands-on activities which meaningful to students</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Learning Contexts</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- everyday life situations which are relevant to students</td>
</tr>
<tr>
<td>- motivating and supporting learning environment</td>
</tr>
<tr>
<td>- school context and policy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Assessment</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- authentic assessment which is part of the learning process, not an extra activity</td>
</tr>
<tr>
<td>- variety of assessment strategies and tools</td>
</tr>
<tr>
<td>- feedbacks from teacher, peers, and self assessment</td>
</tr>
</tbody>
</table>

Figure 2. The guiding principles for STEM education at the primary level
The STEM methods course

The STEM method course was designed for 15 weeks (3 hours/weeks) for preservice primary teachers. The goal of this method course is to model good practice to prepare preservice teachers to acquire relevant pedagogical content knowledge for integrated STEM education.

The preservice teachers will therefore engage with authentic issues or problems through STEM activities. They will develop skills in designing and facilitating STEM learning at the primary level by examining the situations and issues of STEM education and the Thai Basic Education Core Curriculum. They will use specific content knowledge in STEM areas and interdisciplinary processes to design STEM lessons and practice their STEM teaching in classrooms.

There are three instructors including a science, technology and mathematics educator. Their role is as facilitators who work together as a team teaching in the course, to demonstrate the value of cooperation.

Table 1. The outline of the STEM methods course

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Activities</th>
<th>Learning resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The concept and purposes of STEM education</td>
<td>• Pre survey the preservice teacher’s integrated STEM understanding</td>
<td>Research papers and other documents related to the concept and purposes of STEM education</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Small group and whole class discussion</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>The situations and issues of STEM education in Thailand</td>
<td>Brainstorm and presentation</td>
<td>Government and other documents about STEM education in Thailand</td>
</tr>
<tr>
<td>3</td>
<td>• Analyse and criticise The Thai Basic Education Core Curriculum in part which related to STEM • STEM skills • STEM literacy</td>
<td>• Analyse and criticize the curriculum</td>
<td>• The Thai Basic Education Core Curriculum</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Practice STEM skills and interdisciplinary processes</td>
<td>• Research papers and other documents related to STEM skills and interdisciplinary processes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Analyse STEM literacy</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>The specific content knowledge in STEM (1)</td>
<td>Analyse the specific content knowledge in science</td>
<td>• The Thai Basic Education Core Curriculum</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Integrated STEM activities</td>
</tr>
<tr>
<td>5</td>
<td>The specific content knowledge in STEM (2)</td>
<td>Analyse the specific content knowledge in technology and engineering</td>
<td>• The Thai Basic Education Core Curriculum</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Integrated STEM activities</td>
</tr>
<tr>
<td>6</td>
<td>Computing science, coding, and robotics</td>
<td>Practice basic knowledge and skills about computing science, coding and robotics</td>
<td>Outsourcing experts</td>
</tr>
<tr>
<td>7</td>
<td>The specific content knowledge in STEM (3)</td>
<td>Analyse the specific content knowledge in mathematics</td>
<td>• The Thai Basic Education Core Curriculum</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Integrated STEM activities</td>
</tr>
</tbody>
</table>
The last phase of this study is yet to be completed: the presentation of the STEM methods course for critique by the experts, and subsequent modification.

CONCLUSIONS AND SIGNIFICANCE OF THE STUDY

This study is promoting the focus of preservice teachers on the importance of the concept and purpose of STEM education, because STEM can be defined in different ways based on the stakeholder and the context (Radloff & Guzey, 2016). In this method course, the preservice teachers need to develop pedagogical content knowledge about integrated STEM education, and their understanding of interdisciplinary processes. Furthermore, the idea of integrated STEM and the connections among the disciplines are important (Bybee, 2013; Sanders, 2009). The preservice teachers need to design their lessons based on issues or problems which are authentic and real to primary students. This STEM method course is different from other discipline methods courses because it represents the integration of disciplines. The collaboration among science, technology and mathematics educators is represented in STEM teaching and learning (Sanders, 2009).

REFERENCES


ABSTRACT

This paper presents the Indonesia pre-service teachers’ experiences in designing STEM-TPACK learning website. The framework of the technological, pedagogical and content knowledge (TPACK) (Mishra & Koehler, 2006) and STEM (Sanders, 2009) has been synthesised into a theoretical/design framework with work example to guide the pre-service teachers. On the other hand, the framework is employed to examine pre-service teachers’ experiences in learning design. The study reflects the challenges of TPACK formation and interdisciplinary collaboration in developing STEM project. Thirty-eight of second-third year pre-service teachers from science, mathematics, computer science and engineering background formed interdisciplinary groups to design the STEM-TPACK which are aligned with the current secondary school curricula. Data collection includes interview, reflective journal, and observation. The results show that the pre-service teachers faced challenges in communicating their discipline-based content knowledge and knowing in developing the STEM projects. Contextualising and making the connection of their content knowledge with real-world design challenges was difficult for them. Consequently, the pre-service teachers realised that teaching is the complex matter, especially in integrating within TPACK framework. But this was view in positive light for personal epistemic grow. The communicative challenges were catalyst for the creation of lesson design that the pre-service teachers believe are beneficial. This study implies that teacher education curricula may benefits from learning by design employing the TPACK framework with interdisciplinary STEM communities.

Keywords: Pre-service teachers, science and engineering education, STEM, TPACK

INTRODUCTION

The development of science and technology in various aspects of life has in many ways changes the demands of teachers’ competencies. Two key competencies that preservice teachers should begin to develop include ICT integration for subject matter learning and also interdisciplinary STEM project (Chai, Koh & Teo, 2018; English, 2017).

Given that education in secondary school should ensure the students to have knowledge and skills to be successful in the workplace (O’Sullivan & Dallas, 2010), STEM education has been viewed as the means to promote 21st century competencies. When STEM curriculum is well designed, it promotes collaborative and critical thinking skills.

Integrating STEM subjects for 21st century learning is a complex matter that is likely to require high level of skills among teachers. Integration of technology into subject matter
teaching and learning alone has been a challenging task for teachers. Current theoretical framework for the study of ICT integration points to the need for teachers to synthesize and transform their knowledge into technological pedagogical content knowledge (TPACK) (Chai, Koh, & Tsai, 2013), which had been described as a form of contextualised multifaceted knowledge produce through design thinking (Chai, Koh, & Teo, 2018).

While teacher educators has devoted more than a decade of work on various model to facilitate teachers’ TPACK development, recent studies indicate that teachers use of ICT is more teacher-centric rather than the 21st century oriented (e.g., Pringle, Dawson, & Ritzhaupt, 2015). So and Kim (2009) reported that preservice teachers face problem in crafting authentic problems to engender student-centric learning. Nonetheless, Anegli and Valanides (2009) and Chai et al. (2018) has reported models of instructional design processes that has help preservice teachers in designing TPACK.

This study aims to contribute to the research of TPACK by pushing the boundary of a single subject technology integration to the interdisciplinary STEM learning. The acronym STEM (Science, technology, engineering, and mathematics) was first coined in the late 1990s in the United States by the National Science Foundation (Blackley & Howell, 2015). As Parker, Styinski, Bonney, Schillaci, and McAulliffe (2015) have rightly pointed out, STEM and TPACK should be synthesised to guide research in both field. We employed the TPACK framework to design a teacher professional development model for STEM, which could help preservice teachers to develop integrative STEM competencies.

The Next Generation Science Standards reflect the emerging aims of integrative STEM learning as helping students to ask questions and define problems, plan investigation; collect data and interpret data using models and theories, design solution and communicate findings with evidences (Parker et al., 2015). However, developed and developing countries, including Indonesia, face challenges in improving STEM education (Caprile, Palmen, Sanz, & Dente, 2015).

In Indonesia, STEM taught through the separate subjects of Science and Mathematics is highly valued. However, integrated curriculum of two or more disciplines (science, technology, engineering, and mathematics) it is not yet well developed and implemented. The current curricula of Curriculum 2013 requires the integration of technology in all subjects including science and mathematics (Ministry of Education and Culture, 2013). In the curricula, a thematic approach has been used for elementary students, while, in secondary schools, science and mathematics are separate subjects.

However, challenges for implementing a STEM approach remain in both educational settings. The large-scale international comparative studies of Trends in International Mathematics and Science Study (TIMSS) and the OECD’s Program for International Student Assessment (PISA) show Indonesian students score low in science and mathematics (OECD, 2015). This situation may work against integrative STEM. In this context, the further intervention research on STEM need to be developed in order to develop the quality of STEM education in Indonesia from different perspectives, including preservice teachers.

This study focused on engagement of science, engineering, and computer science preservice teachers in lesson designing by integrating TPACK framework in STEM Project. They worked collaboratively in developing the STEM project before designing the lesson in TPACK framework. The learning experiences were explored to understand preservice teachers’ challenges and strategies in the process of STEM-TPACK Design-Based Learning.
METHOD

The STEM-TPACK Design-Based Learning were conducted by design approach for development pre-service teachers TPACK. The teaching model consists three phases of exploring pre-service teachers’ prior knowledge, the development the STEM project, designing the lesson by TPACK framework. These three phases are (see Figure 1):

![Figure 1. STEM-TPACK Design-Based Learning Teaching Model](image)

The teaching model was implemented through two days intensive workshop with thirty-eight of second-third year of the pre-service teachers from science, engineering, computer science, and engineering background. Before the workshop, the pre-service teachers have been grouping into eight groups and exploring the basic principles of STEM project and TPACK framework.

The research focused on two research questions which are the preservice teachers’ challenges in developing collaborative interdisciplinary STEM project and strategies in developing the lesson design in TPACK framework. The data collection was conducted through the interview, reflective journal, and observation throughout the process. the preservice teachers also wrote reflective journals regarding their experiences. The observations were focused on the interaction patterns and conversation in group workshop and discussions The data analysis was conducted through inductive analysis for the theme to emerge from the data sources. The findings below are preliminary.

RESULT AND DISCUSSION

In this sections, the discussion focuses on two research questions of developing the STEM project and lesson designing in TPACK framework.

**Research Question 1: What are challenges in developing collaborative interdisciplinary STEM project?**

In developing the STEM project, the preservice teachers struggled to make connections of all STEM disciplines areas through collaborative working. The eight STEM projects which have been integrated into their lesson design are exoskeleton, wind-turbine generator, building material, green building, piezoelectric, nanogenerator, fruits as alternative energy, and recycled plastic waste. The two challenges are applying the concepts and making the connection of discipline-based content, through collaboration as discussed below.
1. Applying the concepts and making the connection of discipline-based content

The interdisciplinary project provided opportunities for preservice teachers not only for making connection of all subjects, but also for applying the concepts of their own subject. In teacher education program, they learn the subject as a discipline, not in interdisciplinary context. The cross disciplinary challenged them to construct new knowledge, especially in applying the concepts.

"I found that the learning experiences have challenged me in understanding different basic principles of each discipline and its connection. I realised that we have to understand the multidisciplinary approach to solving the problems in daily lives”
(Pre-service teachers 8, Interview, May 10, 2018)

The group discussions also leads to these challenges as illustrated below from group "green building" project

Student 1 I think the green building can be related to the topic in Biology. We learn about the plant that can absorb the pollutant and the insect as the indicator of pollution.

Student 2 It is also related to chemistry concepts in pollutant substances. However, how to integrate with engineering and technology in students’ learning?

Student 3 Ehm...I am thinking of using the software in design the building, we have that subject in engineering

Student 2 But, we don’t have that subject related in secondary school

Student 3 We can implement it in vocational school

These type of conversations were common in the eight groups in order to create the innovative STEM project. While making connection was challenging, the preservice teachers believe that it was meaningful as the interdisciplinary learning provide opportunities for developing higher order thinking skills and connection with other subject areas (Ivanitskaya, Clark, Montgomery, & Primeau, 2002; Maddena, et al., 2013).

"The experiences has challenged my thinking to apply the knowledge and make connections, besides thinking about students’ responds when it is implemented in the classroom" (Pre-service teachers 5, Interview, May 10, 2018)

a. Collaboration skills

In developing the STEM project, the preservice teachers learnt to collaborate and communicate with others from different disciplines. This was described again as challenging because each member have their own ways of viewing and solving the problems.

“We have different discipline background, it was difficult to the connection of our discipline, because everyone would like to put more emphasise of their own discipline. After discussing with the lecturer, we understand that it is important to understand the STEM project and TPACK framework. Finally, we can come out with the ideas after challenging discussions” (Pre-service teachers 15, Reflective Journal, May 9, 2018)

However, the learning experiences have provided an authentic situation of working together with different disciplines as the workforce.
Research Question 2: What are the strategy for developing the lesson design in TPACK Framework?

In developing the lesson, the pre-service teachers need to ensure choosing suitable teaching strategies and technology representations. They developed the website which consisting of the lessons aims, design challenges, students' roles and rules, and activities of each STEM disciplines. Two main strategies in developing lesson design are analysing subject knowledge characteristics with a focus on the learning objectives and students’ engagement though ICT integration.

a. Analysing subject knowledge characteristics with reference to authentic learning and students’ characteristics

In integrating the TPACK framework, they started by discussing the characteristics of content knowledge from each STEM discipline. They realised that the subject application in students’ daily lives required deep understanding of the content knowledge.

“I tried to understand the relation of chemistry knowledge characteristics in the project of building materials that we need to develop. It seems more deep knowledge is required to understand the relationship with chemistry knowledge” (Pre-service teachers 14, Interview, May 10, 2018)

According to Chai and Koh (2017), the first step to develop lesson design in TPACK framework is developing PCK which is centred around finding authentic application and students’ engagement to be relevant to current curricula. They understood that the students will face the challenges in developing the STEM project. Thus they considered students’ prior knowledge and characteristics.

b. Integrating ICT

As the characteristics of TPACK, the preservice teachers need to consider this content knowledge to be integrated with the ICT to guide students learning (Yang & Tsai, 2010).They found it is challenging as they learnt ICT in the separate unit course in their teacher education program. As Chai and Koh (2017) pointed out that that teaching technology skills alone is insufficient to develop capacities for ICT integration in teaching and learning. Even though each group has preservice teachers with ICT background, they have limited understanding in integrating the ICT in students’ learning. They tend to mimic the instructor examples and were not quite able to employ other ICT enabled pedagogical activities.

"It is difficult for me to integrate the ICT in students' learning. I have to learn more, especially concerning enhancing students’ understanding of the concepts” (Pre-service teachers 5, Interview, May 10, 2018)

Even though, the preservice teachers have integrated different technology application to engage the students into STEM project design, such as You Tube, C-map, Autocad, etc, they still need to learn to choose the appropriate applications that are relevant to the subject and students characteristics, and learning objectives. They learnt to construct scaffolding activities to help students, and they also considered how to design interesting website layout.

After these learning experiences, the pre-service teachers realised that classroom teaching is complex. In creating this lesson design, the pre-service teachers realised the different aspects of TPACK that they need to consider. The pre-service teachers realised about their role as designers which encourage them to enhance their lesson design capacity which began to shape their identity as designer (Tracey & Hutchinson, 2016).

“It was complicated learning for me as as I realised the complex process in designing the lesson. I have to think about the content of STEM and students’
As Voogt and McKenney (2017) pointed out, the challenge of teacher education programmes in preparing teachers who are able to design ICT integrated lessons to helping pre-service teachers in constructing different aspects of TPACK. This is essentially a knowledge creation effort (Chai et al., 2018).

CONCLUSION

The science, mathematics, computer science and engineering pre-service teachers have experienced constructing their knowledge and synthesised their TPACK to create the interesting STEM-TPACK design based learning. In developing STEM project, the pre-service teachers have faced the challenges in applying the concepts and making the connection of discipline-based content, besides collaborating with others from different discipline areas. They found the strategies of analysing subject knowledge characteristics, focusing on the learning objectives and students’ engagement, and integrating ICT has helped them in designing the lessons.

The eight-lesson design in the STEM project has been integrated with different learning activities. This study as a catalyst for further research in integrating the STEM project with the TPACK framework. The researchers realised the complex endeavor for the pre-service teachers learning experiences. However, the pre-service teachers have been stimulated to think critically on their TPACK throughout the process which will be powerful for their future practices. In addition to the teacher education program need to reflect on their curricula in order to engage students in the TPACK framework, especially in integrating the educational technology course toward students' learning.

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ABSTRACT

Integrated STEM education has been heralded as a way to help students learn 21st Century skills related to solving real-world problems. However, integrating STEM effectively into classrooms is not a simple task, and there are many aspects of STEM that must be considered. Our prior work has examined teachers’ conceptions of STEM (Ring, Dare, Crotty, & Roehrig, 2017) and ways in which teachers’ conceptions of STEM are reflected in curriculum writing (Ring-Whalen, Dare, Roehrig, Titu & Crotty). This study, contextualised by a professional development (PD) experience, extends our prior research to explore which science and engineering practices three elementary science teachers use when implementing a self-authored integrated STEM curriculum in the classroom, and how teachers’ conceptions of STEM are enacted during this implementation. Classroom implementation videos, field notes, author-created memos, and post observation interviews were qualitatively analysed to better understand teachers’ practices and the role their conceptions of STEM played during implementation of an integrated STEM curriculum. Our findings suggest that science teachers’ conceptions of integrated STEM education impact both general teaching pedagogies as well as the science and engineering practices they use during implementation of STEM curricula.

Keywords: Teacher conceptions, Curriculum, Integrated STEM

INTRODUCTION

Real-world problems cannot generally be solved using knowledge, skills, and ideas framed solely by one of the isolated disciplines taught in K-12 schools. Rather, solving 21st Century problems involves the overlap of multiple disciplines. Educational reform efforts have responded by advocating for the adoption of integrated curricula in K-12 schools as a way to model the real-world, problem-solving skills students must learn to thrive in today’s society (National Research Council [NRC], 2011; The Royal Society Science Policy Center, 2014).

Specifically, there has been a push to integrate science, technology, engineering, and mathematics (STEM) to improve student competencies and to help maintain the competitiveness of the United States in the global workforce (NRC, 2012). However, there are challenges to implementing integrated STEM curricula in classrooms, including the lack
of a cohesive understanding of what STEM integration looks like, both at the conceptual level and in practice (e.g., Bybee, 2013). This is troubling, as research from different content areas has shown that conceptions of teaching influence practice (e.g., Remillard, 2005). Unfortunately, there is little research available that explores this relationship with regard to integrated STEM education. With that in mind, this study aims to answer the research questions: 1) How do three teachers’ practices differ in their individual implementations of an integrated STEM curriculum?; and 2) How, if at all, do teachers enact their conceptual models of integrated STEM education in the classroom when implementing a STEM curriculum?

THEORETICAL FRAMEWORK

We grounded our research in the understanding that teacher beliefs can affect classroom practices (e.g., Remillard, 2005). Pajares (1992) suggested that beliefs are “the best indicators of the decisions individuals make throughout their lives,” (p. 307) and Wallace and Kang (2004) extended this idea to assert that “teacher actions represent one aspect of teacher’s beliefs and should not be perceived as a separate entity from the belief system as a whole” (p. 938). Teachers’ actions in the classroom, then, reflect their beliefs, and examining teachers’ classroom practices provides insight.

Additionally, we focused on how a teacher’s approaches to education reform can be impacted by their understanding of the reform’s content. The worldwide movement toward implementation of integrated STEM education is one such reform (NRC, 2011, 2012). Improving science education through reforms (i.e., STEM education) generally requires the implementation of novel curricula, and curriculum implementation often acts as an innovation in science education (Rogan, 2007).

This implementation can be influenced by a teacher’s beliefs (Czerniak, Weber, Sandman, & Ahern, 1999; Haney & McArthur, 2002). Further, identifying and examining a teacher’s “profile of implementation” can aid in determining the extent to which the ideals of the curriculum are put into practice (Rogan & Aldous, 2005). With this as our basis, we assert that in this study teachers’ decisions in the implementation of their curricula reflect their beliefs about and conceptualisations of integrated STEM education.

METHODOLOGY

Research Design

This study employed an exploratory multiple case study design (Yin, 2014). Each of the three teacher participants represented one case, and the phenomenon of study was each teacher’s practices and enactment of their conceptual model of STEM integration in the classroom. Once individual cases were analysed, cross-case analysis allowed similarities and differences in the enactment of different conceptual models of integrated STEM education to be determined (Yin, 2014).

Data Collection and Analysis

Forty-five K-12 science teachers participated in a 3-week summer professional development (PD) as part of a large 5-year project designed to promote K-12 integrated STEM education using both a STEM integration framework (Moore et al., 2014a) and a Framework for Quality K-12 Engineering Education (Moore, Glancy, Tank, Kersten, & Smith, 2014b).

The PD introduced the use of an engineering design challenge (EDC) as an engaging context in which to frame an integrated STEM unit. Teachers worked in small teams to create
integrated STEM curricula to be used by all members of the team. These curricula were
guided by the six tenets of the STEM integration framework (Moore et al., 2014a). Following
the PD, teachers individually implemented the team-created curricula, refining the finished
product after implementation.

A team of three elementary teachers (Allison, Holly, and Melissa) whose conceptions
of STEM were studied in Ring-Whalen et al. (2018) was purposively selected for this
multiple case study. This team wrote and implemented Improving the Mechanical Claw, a
conceptually well-integrated STEM curriculum consisting of eight lessons. This 5th grade
unit focused on physical science content; specifically, the mathematical and scientific
concepts related to electromagnetism through the incorporation of an EDC that asked
students to design and build an electromagnet to replace the standard mechanical claw used in
common arcade games.

Data collection for this study took place during the school year and consisted of two
primary data sources (classroom observation videos and post interviews), as well as several
secondary sources (field notes and author-created memos).

Analysis of each teacher’s implementation occurred in several phases. First, author-
created memos from classroom implementation videos, field notes, and post observation
interviews were analysed using a combination of deductive and inductive coding techniques
(Miles & Huberman, 1994). The resulting conceptual codes from each teacher’s
implementation of the curriculum were then compared to the NGSS Science and Engineering
Practices (NGSS Lead States, 2013) and Framework for Quality K-12 Engineering Education
(Moore et al., 2014b) to determine which practices were used in their implementation of the
integrated STEM curriculum (Table 1).

The description of each teacher’s conception of integrated STEM education (Ring-
Whalen et al., 2018) was then compared to the conceptual codes describing the corresponding
teacher’s implementation of the integrated STEM curriculum using thematic comparison
(Maxwell, 2013). This helped describe the ways that teachers’ conceptual models of
integrated STEM were enacted in their classrooms. Finally, cross-case analysis (Yin, 2014)
was conducted to determine similarities and differences between the teachers’ enactment of
their conceptions of STEM. This allowed a broader description of how teachers enacted their
conceptual models of integrated STEM education in the classroom to be constructed.

Table 1. Coding Framework

<table>
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<tbody>
<tr>
<td>Asking questions (science) and defining problems (engineering)</td>
<td>Problem and background (POD-PB)</td>
</tr>
<tr>
<td>Developing and using models</td>
<td>Plan and implementation (POD-PI)</td>
</tr>
<tr>
<td>Planning and carrying out investigations</td>
<td>Test and evaluate (POD-TE)</td>
</tr>
<tr>
<td>Analysing and interpreting data</td>
<td>Apply science, engineering, and mathematics (SEM)</td>
</tr>
<tr>
<td>Using mathematics and computational thinking</td>
<td>Engineering thinking (EThink)</td>
</tr>
<tr>
<td>Constructing explanations (science) and designing solutions (engineering)</td>
<td>Conceptions of engineers and engineering (CEE)</td>
</tr>
<tr>
<td>Engaging in argument from evidence</td>
<td>Engineering tools (Etool)</td>
</tr>
<tr>
<td>Obtaining, evaluating, and communicating information</td>
<td>Issues, solutions, and impacts (ISI)</td>
</tr>
<tr>
<td></td>
<td>Ethics</td>
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<td></td>
<td>Teamwork</td>
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RESULTS AND DISCUSSION

Results
In all three cases, teachers’ conceptualisations of STEM were enacted in individual implementations of the *Improving the Mechanical Claw* curriculum. Because their conceptions of STEM were similar going into classroom implementation (Ring-Whalen et al., 2018), there were many similarities in the ways the teachers implemented the unit. However, there were also some unique emphases in each teacher’s implementation, which reflect the subtle differences in their conceptions of STEM. Due to space limitations of the proposal, only the cross-case findings will be presented here.

Curricular Influence
Some of the commonalities identified in the teachers’ implementations related to the *Improving the Mechanical Claw* curriculum itself, which is not surprising as the three teachers co-authored the curriculum. Additionally, the teachers had similar conceptions of STEM, meaning that little negotiation of their conceptions was necessary during development of the curriculum (Ring-Whalen et al., 2018).

For example, the teachers’ conceptions included a strong emphasis on the integration of all four STEM disciplines, resulting in a conceptually well-integrated curriculum. This integration was demonstrated across the teachers’ implementations as well – all four STEM disciplines were represented in their teaching. Additionally, the engineering pedagogies of teamwork, ethics, and communication were used similarly by all three teachers in ways that were well-described in the curriculum. The students worked in ‘engineering teams’ and were required to report back to the client. Each teacher discussed ethics in relation to the efficiency of the claw and balancing player winning with owner profits.

Engineering
All three teachers used the engineering design challenge (EDC) to engage students and contextualise their learning. The EDC was revisited at the start of every lesson, emphasising the importance of engineering in this unit. This points particularly well to Holly’s conception that STEM, and specifically the integration of engineering in a science class, is a good way to engage students in real-world contexts.

Students had been introduced to the engineering design process (EDP) prior to implementation of the *Improving the Mechanical Claw* unit in all three classrooms. However, the EDP was referenced in daily instruction to a different degree between teachers. Allison and Melissa referenced EDP posters (supplied to them in the summer PD) and frequently asked the students which step of the EDP they were engaged in. Holly, however, never explicitly called out the EDP even though she used EDP terminology and implemented the unit in such a way that it mirrored the design process.

Science
For Allison and Holly, the science focus tended to be on practices rather than on science content. Allison’s emphasis on what scientists do and Holly’s emphasis on the steps of an experiment tied to their conceptions that STEM was about exposing students to STEM careers (Allison) and connecting school to the real-world (Holly).

While similar, these were two different ways of legitimising the unit’s activities for students. Melissa placed more emphasis on the science content than the other teachers. This was evidenced in her addition of an extra lesson on circuits at the beginning of the unit. She
also consistently called out specific science content throughout the unit, ensuring that her students understood the science concepts they needed to know in order to successfully complete the EDC.

**Mathematics**

Mathematics was often incorporated in the unit in tandem with technology, perhaps because technology was written into the unit as a way to display and analyse data. Interestingly, Allison walked her students step-by-step through the process of setting up data tables, while Holly and Melissa gave the students more autonomy throughout these portions of the unit. None of the teachers taught any new mathematical concepts during the unit, but the way mathematical content was discussed differed.

While both Allison and Holly dedicated a small amount of time to computational thinking in their units, their emphasis tended to be on procedural rather than conceptual understanding (e.g., steps to take the average of a group of numbers). Melissa, however, tended to emphasise conceptual understanding. The limited use of mathematics in the classroom by all of the teachers aligns with their conceptions that integrating mathematics is difficult. Melissa’s added idea that mathematics, while difficult to integrate, is important in STEM may have contributed to her stronger emphasis on conceptual understanding than the other two teachers.

**Technology**

In the PD, technology was defined as the outcome of an EDC. While the students were asked to create a prototype for an electromagnetic arm as part of *Improving the Mechanical Claw*, the teachers focused more on technology as a digital learning tool during the implementation of the unit. Additionally, there was a strong contrast between the teachers’ integration of technology in their classrooms.

Allison used technology only as a communication tool between the students and the client. Holly included technology as a way to analyse and represent data as well as a learning tool. Melissa incorporated everyday use of iPads, resulting in seamless integration of technology in her classroom. This may have been the result of district requirements for technology integration.

While all three classrooms were one-to-one, only Melissa’s district stressed technology as a classroom expectation for all teachers. While all three teachers’ conceptions of STEM suggest that technology integration is difficult, Melissa did a better job of integrating technology in her classroom than the other two teachers. As with mathematics, this may have been the result of her conception that technology, while difficult to integrate, is important in STEM and something that she wanted to improve in her practice.

**Integrating STEM**

Even though all three teachers’ conceptions of STEM strongly emphasised the importance of connecting the four STEM disciplines, only two of Allison and Holly’s lessons (lessons that extended across multiple days of instruction) included meaningful integration of all four STEM disciplines. Other lessons included integration of two or three disciplines, but it required more than one class-period for these teachers to be able to include three or more disciplines in a meaningful way. Melissa, on the other hand, was able to integrate three or four disciplines consistently, without adding much additional time to the lessons.

**DISCUSSION AND LIMITATIONS**

Teachers’ conceptions and beliefs can impact how curricula are implemented in classrooms (e.g. Remillard, 2005). However, understanding the nature of curricular
implementation is a complex and difficult task. In this study, we focused on how three teachers’ practices differed in their implementations of a single, integrated STEM unit. We then examined how, if at all, these teachers’ conceptions of STEM were enacted during their implementation.

From our study, it is evident that even teachers who have similar conceptions of STEM enact them in different ways. While all three teachers in this study believed that STEM should emphasise connecting science, technology, engineering, and mathematics, they placed different emphases on each of these disciplines. Additionally, we found that small variations in teachers’ conceptions (i.e., STEM connects students to STEM careers and STEM bridges the gap between school and the real-world) can create differences in the way a curriculum is implemented. Although the teachers in this study drew upon the same practices (NGSS Lead States, 2013; Moore et al., 2014a), they emphasised them in different ways.

We found that even when teachers conceptualise integrated STEM as the connection between science, technology, engineering and mathematics, it is not always possible to meaningfully integrate all four disciplines in a single class period. This finding supports previous research suggesting that connecting all four STEM disciplines, and mathematics and technology in particular, is difficult and takes considerable time (Ring-Whalen et al., 2018; Herschbach, 2011).

The teachers all recognised their discomfort in teaching mathematics; however, they also believed mathematics was an important part of integrated STEM and made efforts to integrate it in their units - often as a tool for learning or practicing science. The teachers recognised the difficulty of integrating technology in their implementations as well, resulting in technology being utilised as a learning or teaching tool. This differed from the way technology was introduced in the PD (i.e., a product of engineering) and speaks to the difficulty of defining technology in integrated STEM (e.g., Herschbach, 2011).

These findings suggest that teachers need support through high quality PD to effectively integrate content in which their background knowledge is limited (e.g. Ejiwale, 2013). In particular, PD that focuses on improving teachers’ content knowledge and understanding of the disciplines of STEM is needed.

Although the teachers conceptualised STEM with engineering as a way to engage students in learning and connect that learning to more than just content, they did not always make explicit connections between what the students were doing and engineering practices. Perhaps the teachers were less comfortable with some of the language of engineering, or perhaps they simply assumed they were making these connections. This may be because teachers felt they were explicitly exposing students to engineering practices (i.e., the intentionality was there), but those connections were never made by the students.

Making explicit connections for students is important, particularly in interdisciplinary education (e.g., Cohen, Patterson, Kovarik, & Chowning, 2013). However, these findings support literature that has found making explicit connections can prove to be difficult for teachers implementing STEM curricula (e.g., Ring-Whalen et al., 2018; Cohen et al., 2013). To this end, PD that supports teachers in making explicit connections between the language and disciplines of STEM is necessary (e.g., Ejiwale, 2013).

CONCLUSIONS AND SIGNIFICANCE OF THE STUDY

Integrated STEM education is an education reform effort that has the potential to impact teachers and students in positive and significant ways. This multiple case study allowed several meaningful implications for integrated STEM education to emerge.
individual cases were analysed to determine how three teachers’ practices differed in their individual implementations of an integrated STEM curriculum. Understanding these differences will allow curriculum developers to better understand how curricula, once written, may be implemented in classrooms. It may also provide information about student performance in integrated STEM classrooms, although future study connecting integration practices and student performance is needed. Second, the cross-case conclusions are important for teacher educators, district administrators, and those involved in creating and facilitating PD surrounding STEM integration.

Understanding how teachers enact their conceptions of integrated STEM through instruction will allow teacher educators and district administrators to better support teachers implementing STEM curricula. In particular, these individuals need to be aware that mathematics and technology are areas of concern. Similarly, understanding how to make explicit connections between STEM disciplines can also be difficult for teachers. Identifying subtle differences in science and engineering practices is important for both teachers and students. Understanding these challenges will allow PD facilitators to understand how to construct PD to meet the needs of teachers responsible for implementing STEM curricula.

Finally, this study provided a snapshot of one team of teachers implementing a co-authored integrated STEM unit in their classrooms. Further large-scale studies related to science teacher practices used in integrated STEM education are needed.

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AN EXPLORATION OF THE PROCESS OF BECOMING A STEM MIDDLE SCHOOL

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ABSTRACT

STEM jobs are growing at faster rates than there are students graduating with these degrees (Vilorio, 2014). Thus, increasing diversity within the STEM is critical to meet STEM workforce demands. Creating STEM schools is an increasingly common approach to diversifying participation in STEM. This research explored how teacher leadership STEM teams can facilitate the process of becoming a STEM school through examination of the teams’ work and reflection on how they prioritise and work toward this goal. This multiple case study included three urban middle schools and explored the work of the STEM leadership teams during their first year working toward the goal of becoming an inclusive STEM middle school. The work of the STEM teacher leadership teams was examined through analysis of teachers’ responses to a modified STEM School Inventory for the 14 critical components for Inclusive STEM High Schools (Lynch et al., 2017). In addition, the STEM leadership team meetings and an end of year focus group reflection on the STEM Inventory data were qualitatively coded. The cases revealed the importance of a supportive school administration, importance of developing STEM curriculum connected to students’ experiences and interests, and the need for professional learning to promote reform-based teaching practices.

Keywords: Inclusive STEM schools, STEM teacher leadership, STEM curriculum development

INTRODUCTION

STEM (Science, Technology, Engineering, and Mathematics) Education has received considerable attention over the last decade. Within the United States, national calls for improving the quality of STEM education are driven by STEM workforce needs, as the United States is not producing adequate numbers of STEM graduates to meet the growing number of positions within these fields (Vilorio, 2014). Furthermore, in order for students to become informed citizens who can make sense of this information rich, technologically advanced environment, STEM literacy is necessary, even for those not working in a STEM field (Honey, Pearson, & Schweingruber, 2014).

Within the United States, policy documents call for STEM education access for all students (National Research Council [NRC], 2011; President’s Council of Advisors in Science and Technology [PCAST], 2010). Yet, females and students of colour remain underrepresented in most STEM fields and a wide gap in STEM achievement persists
between white students and underrepresented minorities when compared to population demographics and the respective representation of these groups in the STEM fields (National Center for Science and Engineering Statistics [NCSES], 2017). Thus, increasing STEM participation for females and student of colour could help meet market needs and ensure access to STEM fields for all students. One suggestion for providing quality STEM educational experiences to more students in the K-12 setting is to increase the number of STEM schools in geographic areas serving diverse student populations. The PCAST recommended, “The Federal Government should promote the creation of at least 200 new highly-STEM-focused high schools and 800 STEM-focused elementary and middle schools over the next decade, including many serving minority and high-poverty communities” (2010, p. 10) to make STEM accessible to a broader student population in the United States.

Many of the STEM schools within the United States were created with a STEM specific mission (Means, Confrey, House, & Bhanot, 2008; Toefel-Grehl & Callahan, 2014). However, in order for STEM to be available to a broader population of students, there must be other ways to foster STEM programming within public neighbourhood schools other than shutting down and reopening schools with a STEM focus. Teachers are a valuable resource in shaping school culture and practices (Liberman & Freidrich, 2010), thus finding ways to develop STEM programming through teacher leadership teams within schools is a possible mechanism for developing inclusive STEM schools. Existing research has primarily focused on inclusive STEM high schools and examines schools that are well established (e.g. Lynch et al., 2017). There is little research on the process of becoming an inclusive STEM school. Thus, this study attempted to better understand how teacher leadership STEM teams can drive STEM integration in individual and systematics ways within their schools and inform those considering starting an inclusive STEM middle school. The research question that guided this work was:

In what ways do teachers on leadership STEM teams describe critical components for STEM in their schools and how are these components prioritised within the team for STEM integration efforts in these spaces?

LITERATURE REVIEW

Most of the existing research has focused on STEM high schools, yet middle school is a time when students are vulnerable to general academic risk and students’ attitudes toward school can become more negative (Eccles et al., 1993). In addition, individuals start thinking about career choices during early adolescence (Aurger, Blackhurst, & Wahl, 2005). Students who expressed an interest in science-related careers during their 8th grade year were almost two times more likely to earn a degree in the life sciences and more than three times more likely to earn degrees in physical science and engineering than students without similar aspirations (Tai, Lui, Maltese, & Fan, 2006). Given, that interest in early adolescence can predict STEM persistence later in life and STEM programs have the potential to support focusing on this interest, middle school is an ideal time to intervene with STEM-based schools.

There is great variation in the selection and recruitment of students for STEM schools in the United States, and this directly affects who is exposed to meaningful STEM experiences (Means et al., 2008). The Committee on Highly Successful Schools or Programs for K-12 STEM Education (NRC, 2011) identified three different STEM school types: (1) Selective STEM high schools, (2) Inclusive STEM high schools, and (3) STEM-focused technical and career readiness schools. Selective STEM High Schools are organised around the STEM disciplines and have highly selective entrance criteria. While Inclusive STEM
High Schools (ISHS) are also organised around one or more of the STEM disciplines, they have no selective admissions criteria and are focused on serving students from underrepresented/minority backgrounds. ISHSs aim to provide experiences similar to those students would encounter at selective STEM schools, while serving a broader student population. STEM-focused technical and career readiness schools are typically programs within comprehensive high schools and career academies. This study focused on ISHSs because they provide access to authentic STEM learning experiences for diverse student populations.

Research on effective Inclusive STEM school models by Lynch et al. (2017) identified 14 critical components of successful inclusive STEM high schools (see Table 1). However, the ways in which these components develop over time as STEM schools are established is not known. While these critical components provide an aspirational goal for schools embarking on becoming a STEM school, there is a need to better understand the pathways to developing quality across all 14 critical components. Thus, these 14 critical components served as the conceptual framework for the study as they represent a long-term goal of success for emergent inclusive STEM schools.

<table>
<thead>
<tr>
<th>Critical Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – College Prep STEM Focused Curriculum for all</td>
<td>Schools need STEM-Focused curriculum with strong courses in all four STEM areas and intentionally integrated subject domains</td>
</tr>
<tr>
<td>2 – Reform Instructional Strategies</td>
<td>Reform-based instructional strategies and project-based learning were central to classrooms</td>
</tr>
<tr>
<td>3 – Integrated, Innovative Technology Use</td>
<td>Integrated and innovative opportunities for technology use connect students with STEM models, databases, and research materials</td>
</tr>
<tr>
<td>4 – STEM-rich, Informal Experiences</td>
<td>Opportunities for blended formal/informal learning were readily available to students (i.e. apprenticeships and mentoring in partnership with business or industry).</td>
</tr>
<tr>
<td>5 – Connections with Business, Industry, and World of Work</td>
<td>Authentic STEM partnerships that facilitated apprenticeships, mentoring, and out-of-school projects</td>
</tr>
<tr>
<td>6 – College Level Coursework</td>
<td>Early college-level coursework was available and schedules were flexible to allow students to take college classes</td>
</tr>
<tr>
<td>7 – Well-Prepared STEM Teachers and Professionalised Teaching Staff</td>
<td>Well-prepared STEM teaching staff with have advanced STEM content knowledge and/or work experience in STEM fields.</td>
</tr>
<tr>
<td>8 – Inclusive STEM Mission</td>
<td>The schools emphasise goals of recruiting and retaining students from historically underrepresented groups into the STEM fields.</td>
</tr>
<tr>
<td>9 – Flexible Autonomous Administration</td>
<td>Schools that had more autonomy to conduct their business according to their mission were better able to meet the goals of their STEM programming.</td>
</tr>
<tr>
<td>10 – Supports for Underrepresented Students</td>
<td>Extra support programs are readily available for addressing differences in student readiness with content material.</td>
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</tbody>
</table>
Leadership establishes trust with teachers, students, parents, and the school community. Leadership has a clearly articulated vision that is communicated to the school community.

Students and staff feel a sense of personal and intellectual safety. School values and collaboration between students are apparent.

Students and teachers have a sense of personal and professional agency. Open communication between the school and parents exists.

This study employed an exploratory multiple case design (Yin, 2013), contextualised within STEM program development. The multiple cases under examination were three communities of teachers who participated in STEM teacher leadership teams within three different school contexts. The three schools were vastly different in terms of leadership structures and landscape for STEM, which called for a multiple case design. The three schools were participating in a grant project supporting the development of STEM middle schools in a large, urban district in the Midwestern United States. A local university partnered with school leaders in these schools to support the teacher leadership STEM teams at each school site. A STEM education graduate student was embedded within each STEM team throughout the duration of the grant. An overview of the three middle schools and the associated STEM teacher leadership teams is provided in Table 2. All names are pseudonyms.

<table>
<thead>
<tr>
<th>School</th>
<th>Number of Students</th>
<th>Student demographics</th>
<th>Standardised test scores</th>
<th>STEM Team Members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somerville</td>
<td>898</td>
<td>39% White 31% Black 16% Hispanic 5% Asian 9% American Indian Free/reduced lunch 62%</td>
<td>Reading: 49.6% proficient Science: 37.5% proficient Mathematics: 45% proficient</td>
<td>Seven teachers (science, mathematics, engineering, multi-media)</td>
</tr>
<tr>
<td>Noether</td>
<td>390</td>
<td>7% White 87% Black 2% Hispanic 2% Asian 1% American Indian Free/reduced lunch 81%</td>
<td>Reading: 4.8% proficient Science: 11.4% proficient Mathematics: 8% proficient</td>
<td>Nine teachers (Assistant principal, STEM coordinator, science, mathematics, engineering, language arts, social studies)</td>
</tr>
<tr>
<td>Noddack</td>
<td>560</td>
<td>19% White 52% Black 19% Hispanic, 6% Asian 5% American Indian Free/reduced lunch 82%</td>
<td>Reading: 31.1% proficient Science: 24.6% proficient Mathematics: 24.7% proficient</td>
<td>Six teachers (Science, mathematics, engineering, language arts, social studies)</td>
</tr>
</tbody>
</table>
Data Collection

Data collection occurred throughout the first year of the funded project, as the STEM teacher leadership teams commenced work toward becoming an inclusive STEM school. Data collection measures included: (i) teacher survey responses to the STEM School Inventory which was based on the 14 critical components for Inclusive STEM High Schools (collected in March), (ii) transcripts of STEM teacher leadership team meetings (monthly throughout the academic year), and (iii) a focus group where the member of the STEM teacher leadership reflected on their responses to the STEM School Inventory (May). During the focus group, teachers ranked the critical components in order of perceived importance for becoming a STEM school and discussed their work over the year related to the critical components.

Data Analysis

First, the STEM Inventory survey data was consolidated into graphical form to provide a visual of how the critical components were represented in each school to frame the STEM development process and acts of STEM integration in each school. Next, the rank orders of importance from the focus group were averaged for the team and scaled to match the scale for the survey responses. The data was consolidated in double bar graphs to visually represent both the strength of the critical components and level of deemed importance for the components in each school.

Focus group data was then coded deductively from the critical components to analyse how each team’s STEM integration efforts mapped onto components of effective STEM schools. The last phase of analysis consisted of coding the STEM team meeting transcripts around converging and diverging evidence for the themes identified in the focus group and STEM inventory data.

RESULTS

Sommerville

The responses to the STEM Inventory and the Sommerville teachers’ ranking of importance of each critical component for becoming a STEM school are provided in Figure 1.

![Figure 1. Sommerville teacher’s survey responses for indicator strength and relative importance of critical components for STEM.](image)

There was strong support for STEM from the administration; however, Sommerville teachers reported that there were too many competing initiatives for STEM to become a
priority. Teachers identified needing more traditional leadership hierarchies to prioritize STEM in ways that would afford more teacher collaboration across content areas in order for their work to be meaningful. As such, they ranked critical component nine (administrative structures) as the single most important component for becoming a STEM school. While teachers appreciated the agency they were afforded to develop their own STEM program, they needed more defined roles, accountability, and timelines. This was compounded by the teacher leader, Mr. Kuhl, being unwilling to assume a leadership identity and guide the work of the team.

Teachers also viewed critical components 1 and 2 (STEM curriculum and project-based learning) as critical. However, while several team meetings culminated in excitement and interesting STEM curricular ideas, the teachers were not able or willing to act on their ideas. They pushed back against the lack of time for collaboration and time needed for other school initiatives. Ironically, these other initiatives were grounded in project-based and interdisciplinary philosophies, but teachers were not able to align their nascent views of STEM with these other initiatives and Mr. Kuhl did not have the leadership capacity to coalesce the team around STEM curriculum writing. Lack of commitment to STEM curricular work was also influenced by teachers differing views on critical component 8 (inclusive STEM). While some viewed STEM as motivating for all students, Mr. Kuhl and others firmly believed that students should self-select into STEM experiences, seeing STEM as more of a privilege for motivated and high performing students. As a result, the only STEM programming planned and implemented by the team was a STEM Community night open by application only, for a limit of 20 students.

Noether

The responses to the STEM Inventory and the Noether teachers’ ranking of importance of each critical component for becoming a STEM school are provided in Figure 2.

![Figure 2. Noether teacher’s survey responses for indicator strength and relative importance of critical components for STEM.](image)

Noether was specifically developed as a ninth grade STEM academy within the larger school structure. Thus, there was significant support from the administration, and the assistant principal, a former high school science teacher, worked directly with the STEM team on developing STEM initiatives. In addition, all teachers within the STEM academy were part of the STEM leadership team. The direct involvement of school administration to support the team was noted by all teachers and reflects their high ranking for the importance of critical component 12 (responsive leadership). This support was evident in many ways,
including writing grants and supporting a Maker’s Space and technology for students including classroom sets of Chromebooks, probeware, and 3D printers.

The focus at Noether was to think about STEM through Project-Based Learning (PBL) and develop interdisciplinary curriculum across content domains to make learning more relevant to students lived experiences. Throughout the year, the STEM leadership focused on helping teachers to develop student-centred pedagogies necessary for successful STEM implementation. Thus, it is not surprising that the teachers ranked critical component 2 (reform-based practices) as a strength. Teachers also ranked critical component 1 (STEM Curriculum) and 13 (Positive School Culture) as the most important indicators in their vision for becoming a STEM school. The Noether teachers were strongly committed to a school culture that served all students, with students at the heart of the team’s decision-making about curriculum and STEM activities.

Noddack

The responses to the STEM Inventory and the Noddack teachers’ ranking of importance of each critical component for becoming a STEM school are provided in Figure 3.

![Figure 3. Noddack teacher’s survey responses for indicator strength and relative importance of critical components for STEM.](image-url)

There was not a strong commitment for becoming a STEM school from the administration, yet the teachers were individually motivated to develop STEM opportunities for students and they were allowed the freedom to develop these initiatives within their STEM teacher leadership team. They collectively had the sense that leadership structures (critical components 9 and 12) in the school had flattened traditional hierarchies and felt agency to try new STEM initiatives in their classes without consulting the administration.

Critical component 1 (STEM curriculum) was ranked as most important by the Noddack team, so it was not surprising that they dedicated most of their collaborative time to designing STEM curriculum across the disciplines. The teachers implemented many STEM units developed by small interdisciplinary teams within the larger team. This collaboration also allowed teachers to make connections to the work others on the team were doing on a regular basis, even when there were not full interdisciplinary projects happening. This curricular work was supported by the teachers’ value of critical component 5 (real world STEM partners). The teachers were personally invested in seeking out professional development opportunities and had forged many different partnerships with professional organisations outside of the school to support their STEM work.
CONCLUSIONS

The three cases provide important information about the development of inclusive STEM schools. First, the role of school administration is critical for the success of a school-wide STEM initiative. Informed and active administrative participation, as in the case of Noether, provided a strong platform for building a common vision and professional learning toward quality STEM programming. Simply flattening hierarchies, and providing teachers with autonomy as a STEM team, resulted in many individual and small-scale STEM activities at Noddack, but without administrative support, no systematic school-wide STEM activity was possible. Second, all three teams focused on the development of STEM curriculum. This work allowed the teachers to draw on each other’s strengths and co-develop their vision for STEM. It also allowed them to focus on their students and provide authentic and motivating contexts that would further the mission to be an inclusive STEM school responsive to student needs. Third, successful implementation of STEM requires that teachers are able to implement reform-based pedagogies and that STEM leaders are able to support reform-based teaching within their team.

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PROMOTING COGNITIVE CONFLICT THROUGH INSTRUCTIONAL STRATEGIES: GENDER DIFFERENCE IN PHYSICS LEARNING IN SECONDARY SCHOOLS

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ABSTRACT

In Tanzania, gender inequity, access parity, poor training in study skills and poor foundation in the sciences from primary school level influence the academic performance of females. Because of this learning, attitudes, participation, motivation and achievement especially for females in science subjects and physics in particular becomes unproductive and not meaningful as it encourages rote learning. Researches suggests use of instructional strategies that promote cognitive conflict result in females experiencing inadequacy in their existing knowledge through conceptual change. Studies reveal computer simulations to be among more productive experience over traditional instructional strategies. Although many studies demonstrate the benefits of computer simulations in physics and other science subjects, there is scarcity of empirical research in the Tanzanian context demonstrating the effect of computer simulations on motivating secondary school females in learning physics. ‘Are there differences among male and female students’ in physics learning after computer simulation?’. The focus of this study is on form two secondary school students aged 13 – 16 years from the Tanzanian context. Mixed method in data collection was used but quantitative results are reported as preliminary findings. After computer simulation female students’ self-efficacy and self confidence in learning was statistically significant compared to males. Higher score is an indication that females generate conceptual conflicts and as a result promote conceptual change. Further research results would be valuable in extending upon this work.

Keywords: Motivation, engagement, computer simulation, self efficacy, self confidence in learning

INTRODUCTION

Over the last six decades, much of the research in science education and in cognitive science worldwide has focused on students’ prior knowledge and conceptions primarily in the natural sciences. During this period many studies concentrated on investigating the development of students’ pre-instructional conceptions regarding science concepts.

Because of these studies, science educators (e.g. Driver & Easley, 1978) as cited by Vosniadou (2012) became aware that students bring to science learning, frameworks that are robust and often difficult for teachers to change or eliminate. The results from these studies guided science educators to regard learning as the restructuring of existing knowledge and the constructing of new models to fit new understandings and experiences (Chaimala, 2009).
As reported by Chambers and Andre (1997) prior to the 1990s, research had not examined the relationship between gender and conceptual change. Few studies that did include gender indicated that gender played a role in some aspects of knowledge restructuring Pearsall, Skipper, and Mintzes (1997). Pearsall et. al. (1997) revealed different learning styles among males (i.e., meaningful or deep learning characteristics) and females (i.e., rote learning or surface learning characteristics). Hence, the literature calls for further research on knowledge construction in the natural science (e.g., physics) to find out how conceptual change might meaningfully be mediated among gender groups.

Reports from some of African countries where gender segregation data are available show that the number of females in science is low compared to males. The few females who enroll in science subjects register low performance (Ajai & Imoko, 2015). Comparable evidence by Ogunleye (2001) from science education reforms of the 1980’s reveals both pedagogical practice and the presentation of science in many classrooms reflected masculine social and cultural stereotypes.

In Tanzania, examination reports for the past seven years indicate very slow improvement in the performance of females in physics (e.g., CSEE, 2009 -2014). Gender inequity and access parity, poor training in study skills and poor foundation in the sciences from the primary school level influence the academic performance of females (MoEVT, 2010). As revealed by (Mpuchane, 2011) the experiences in turn influence attitudes, participation, motivation and achievement especially for females in science subjects and physics in particular. This is especially in a classroom situation where the females get confronted with instructions they do not relate to (see Chambers & Andre, 1997). As a result of this situation, learning becomes unproductive and not meaningful as it encourages rote learning.

Employing instructional strategies that promote cognitive conflict would potentially result in females experiencing inadequacy in their existing knowledge; hence meaningful experiences through the process of conceptual change (Novak, 2002). Some studies by Bell and Smetana (2008), Tao and Gunstone (1999), Trundle and Bell (2010) reveal computer simulations to be a more productive experience over traditional instructional strategies in inducing cognitive dissonance by simulating the consequences of students' misconceptions.

PROBLEM STATEMENT

Although many studies indicate the benefits of computer simulation in promoting knowledge construction in physics learning, the review of literature reveals limited empirical evidence or no such study in the Tanzanian context has been carried out to examine the extent to which computer simulations can improve female students’ self-efficacy in physics learning. Examining knowledge construction among female students through their participation in physics learning may provide insights on how students’ self-efficacy in learning is likely to be enhanced through use of current instructional strategies.

This research examined different motivation scales towards physics learning. Specifically, this research is guided by the following question:

*How might male and female students’ self-efficacy in physics learning compare after computer simulation experience?*
THEORETICAL FRAMEWORK

This study employed Posner, Strike, Hewson, and Gertzog (1982) conceptual change perspective that builds on Vygostsky’s (1978) theory of social constructivism that views learning as a social activity in which learners make meaning through both individual and social activities. The social constructivism is the result of its development from the earlier theory's limitation to consider the social dimension. According to Driver, Asoko, Leach, Scott, and Mortimer (1994) a social constructivist perspective recognises that learning involves being introduced to a symbolic world. Thus, as socially constructed, Driver et al. (1994) add knowledge and understanding in this case including scientific understandings are constructed when learners engage socially in discussions and activities.

Employing Driver et al.’s (1994) perspective and linking it with social constructivism, meaning making in scientific learning becomes a dialogic process involving learners - in conversation. Also as stated by Driver and Erickson (2008), learners construct knowledge using their prior knowledge and experiences. Various constructivist theories have been applied in understanding and interpreting science learning or knowledge construction in science. Conceptual change theory (Posner et al., 1982) is a prominent framework for understanding the learning of science concepts. According to Appleton (1997) the main tenet of constructivist theories is that learners employ existing ideas to make sense of new experiences and information.

Under this theoretical examination, conceptual change has been the most significant learning model to interpret students' alternative conceptions. This is because as Kang, Scharmann, Noh, and Koh (2005) stress, knowing students' alternative conceptions is an essential starting point to develop strategies for introducing new scientific concepts. Embodied by the constructivist ideals, conceptual change model by Posner et al. (1982), has been key to designing and implementing effective learner centred classroom instruction.

The classical approach to conceptual change has over the decades guided research and instructional practices in science education (Vosniadou, 2012). Within the classical approach, cognitive conflict has been key to achieving conceptual change (Vosniadou, 2012). Studies by Baser (2006) reveal that students’ alternative conceptions that are grounded in everyday experiences are resistant to change. Baser (2006) has cited physics as one of the areas where most of the students’ prior knowledge remains unchanged despite receiving instruction aimed at eliminating their alternative conceptions.

Students' socio-cultural identities including gender are shown to affect the way they learn (Hodson, 1998). The socio-cultural practices in which learners’ experience learning can be interpreted as different ways of "seeing things" into what Claxton (1990) terms "stances" which tend to guide individual students and their group activities. As deduced by Nashon and Adler (2012) adherence to the stances becomes the makeup that guides students' learning behaviour in such a way that confronting students with information contrary to their belief or theory may partially modify or resist to change. This presents a challenge not only for the conceptual change family but also science educators in terms of research and practice in teaching and learning science. A need to create a context of social interaction where the learner experiences inadequacy or instability of his/ her current belief or theory is required.

Secondary school girls’ views of science learning

As it has been argued and as contextualised, females' social cultural factors affect the way they learn. It is possible that some female students’ traditional views do impact their way of learning. Translating from Jegede, 1997; Lagoke, Jegede, & Oyebanji, 1997; Williams et al., 2012) statement and also drawing from Chambers and Andre (1997), there is a possibility
that cultural practices influence traditional African approach to traditional 'western' science. But making a more notable global view is the belief that there exists an authority to knowledge and that science knowledge is sacred, accessible only to people with special understanding (e.g., male students) (Jegede, 1997).

It can be suggested that employing constructivist teaching strategies (e.g., Chen, Pan, Sung, & Chang, 2013; Tao & Gunstone, 1999) coupled with computer simulations to induce cognitive dissonance (Kimmons, Liu, Kang, & Santana, 2012; Tao & Gunstone, 1999). Ronen and Eliahu (2000) can help to bridge the gap between theory and reality.

**RESEARCH DESIGN**

This is an interpretive case study approach (Merriam, 1998) used mixed methods of which only quantitative analysis are reported. The physics content on motion in a straight line was selected from the Tanzanian physics syllabus (MoEVT, 2010). Nine classes of form two students (N=265), male (n=154) and female (n=111), students from four private secondary schools were selected to participate in the study.

To find out the validity of the instruments, it was piloted to a sample of 50 students. The questionnaire was then administered prior to the simulation activity and then after the activity. The simulation program was adopted from PhET, University of Colorado, [https://phet.colorado.edu/en/simulations/category/new](https://phet.colorado.edu/en/simulations/category/new).

Before conducting the simulation activity, the teacher provided essential information about the content on motion in a straight line. Students used the results obtained during simulation for the distance, velocity and time to compare with the calculated results in the classroom using the three key equation of motion which are inclusive of velocity-time, position/distance-time, and velocity-position as prescribed in the textbook.

Data analysis included descriptive statistics, tests for reliability, paired sample t-test between pre and post test to compare the difference in self-efficacy, for SMTSL and self confidence in learning for SSSCL dimensions. All negatively worded items were reverse coded.

**RESULTS AND FINDINGS**

The Cronbach’s alpha (α) reliability measure of the entire questionnaire was 0.80 prior to intervention and 0.86 afterwards, whereas for each reported subscale it ranged from 0.66 to 0.76 for the before scale (BS) and 0.67 to 0.77 for the after scale (AS) for the whole class (Table 1).

The SE for female was 0.62 before and 0.63 after; and for male the SE was 0.68 before and 0.70 after.

<table>
<thead>
<tr>
<th></th>
<th>SE</th>
<th>SeCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS</td>
<td>0.66</td>
<td>0.76</td>
</tr>
<tr>
<td>AS</td>
<td>0.67</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Note: BS: before simulation; after simulation(AS) for self efficacy(SE), self confidence in learning (SeCL)
A paired t-test showed a significant change in SE scores for females before simulation \((M=3.51, SD=0.67)\) to \((M=3.87, SD=0.67)\) after simulation (see Table 2), \(t(110) = -5.01, p<0.05\) (see Table 3), whereas for males SE before simulation \((M=3.56, SD=0.67)\) to \((M=3.76, SD=0.78)\) after simulation (see Table 2), \(t(153) = -3.3, p<0.05\) (see Table 3).

Table 3 shows the mean increase in self-efficacy scores for females is -0.362 with a 95% confidence interval (CI) ranging from -0.505 to -0.219. The eta-squared \((\eta^2=0.19)\) indicated a large effect size. Whereas for males, the mean increase is -0.196 with 95% confidence interval (CI) ranging from -0.314 to -0.078. The eta squared \((\eta^2=0.07)\) indicated medium effect size.

The attribute of learning on self confidence in learning (SeCL) showed a remarkable increase in the mean score for females from \((M=3.06, SD=0.51)\) to \((M=3.77, SE=0.51)\) (see Table 2), with the difference -0.711 with a 95% confidence interval ranging from -0.849 to -0.572, showing a significant at \(t(110) = -10.14, p<0.05\), and represents still a large effect size, \(\eta^2=0.49\) (see Table 3). For males \((M=3.19, SD=0.62)\) to \((M=3.77, SD=0.55)\) (see Table 2), with a difference -0.585 with a 95% confidence interval ranging from -0.706 to -0.464, showing a significant at \(t(153) = -9.58, p<0.05\), where eta squared \((\eta^2=0.38)\) represents a large effect size (see Table 3).

The overall preliminary analysis shows a highly significant increase in the mean scores in self-efficacy and self confidence in learning for females score from \((M=3.28, SD=0.45)\) to \((M=3.82, SD=0.46)\), the difference of -0.54 with a 95% confidence interval ranging from -0.65 to -0.43, significant at \(t(110) = -9.73, p<0.05\) with a large effect size, \(\eta^2=0.47\) (see Table 4). Whereas for males \((M=3.38, SD=0.51)\) to \((M=3.77, SD=0.48)\), the difference of -0.39 with a 95% confidence interval ranging from -0.48 to -0.30, significant at \(t(153) = -8.76, p<0.05\), with eta squared\((\eta^2=0.34)\) showing large effect size (see Table 4).

**Table 2. Paired Samples statistics for male \((n=154)\) and female \((n=111)\) groups for each scale before and after simulation for each subscale**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Mean(M)/Std . Deviation (SD)</th>
<th>Standard Error(SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>SE BS 3.56/0.67 0.05</td>
<td>AS 3.76/0.78 0.06</td>
</tr>
<tr>
<td></td>
<td>SeCL BS 3.19/0.62 0.05</td>
<td>AS 3.78/0.55 0.04</td>
</tr>
<tr>
<td>Female</td>
<td>SE BS 3.51/0.67 0.06</td>
<td>AS 3.87/0.67 0.06</td>
</tr>
<tr>
<td></td>
<td>SeCL BS 3.06/0.51 0.05</td>
<td>AS 3.77/0.51 0.05</td>
</tr>
</tbody>
</table>

Self-efficacy(SE) and Self confidence in learning (SeCL); Before simulation (BS) and After simulation (AS)
### Table 3. Paired Samples test on effect of computer simulation for BS-AS among males and females

<table>
<thead>
<tr>
<th>Gender</th>
<th>Scale</th>
<th>M</th>
<th>SD</th>
<th>SE Mean</th>
<th>Lower</th>
<th>Upper</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>SE</td>
<td>-.196</td>
<td>.740</td>
<td>.060</td>
<td>-.314</td>
<td>-.078</td>
<td>-3.281</td>
<td>153</td>
<td>.001**</td>
</tr>
<tr>
<td>Female</td>
<td>SE</td>
<td>-.362</td>
<td>.761</td>
<td>.072</td>
<td>-.505</td>
<td>-.219</td>
<td>-5.010</td>
<td>110</td>
<td>.000**</td>
</tr>
<tr>
<td>Male</td>
<td>SeCL</td>
<td>-.585</td>
<td>.758</td>
<td>.061</td>
<td>-.706</td>
<td>-.464</td>
<td>-9.577</td>
<td>153</td>
<td>.000**</td>
</tr>
<tr>
<td>Female</td>
<td>SeCL</td>
<td>-.711</td>
<td>.738</td>
<td>.070</td>
<td>-.849</td>
<td>-.572</td>
<td>-10.139</td>
<td>110</td>
<td>.000**</td>
</tr>
</tbody>
</table>

**p<0.05

### Table 4. Overall paired sample t -test on effect of computer simulation for SE and SeCL scales

<table>
<thead>
<tr>
<th>Gender</th>
<th>M</th>
<th>SD</th>
<th>SE Mean</th>
<th>Lower</th>
<th>Upper</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>BS-AS</td>
<td>-.39</td>
<td>.55</td>
<td>.044</td>
<td>-.48</td>
<td>-.30</td>
<td>8.76</td>
<td>153</td>
</tr>
<tr>
<td>Female</td>
<td>BS-AS</td>
<td>-.54</td>
<td>.58</td>
<td>.055</td>
<td>-.65</td>
<td>-.43</td>
<td>9.73</td>
<td>110</td>
</tr>
</tbody>
</table>

**p<0.05

### DISCUSSION

The preliminary findings are evidence that differences in SE and SeCL in physics learning exist among males and female students after simulation. The paired t-test used to determine the relationship between SE and SeCL shows a significant difference between males and females in these two scales (see Table 4). There is a significant change in mean score from a pre- to post simulation for a self-efficacy (SE) subscale, associated with increase in females’ perception after participating in simulation activity as shown on Table 3.

Tuan, Chin, Tsai, and Cheng (2005), revealed that an increase in student’s self-efficacy after simulation is on students believe they have, on capability of accomplishing learning task. Furthermore, empirical evidence from Pintrich, Marx, and Boyle (1993) indicate that self-efficacy as a motivational belief influence students’ cognitive engagement and in turn influence conceptual change.

Other preliminary findings drawn from self confidence in learning scale shows a statistically significant difference between males and females after using simulation which
shows highly significant at p<0.05 as also noticed in Table 3. Bandura, (1991) defines self-confidence as one’s belief in their ability to succeed and a high self-efficacy in accomplishing is associated with high confidence in responding to the task. It is believed that students who have low self-efficacy for accomplishing a task would tend to respond to items with less confidence while those with high self-efficacy tend to respond to items with high self-efficacy (Bandura, 1991).

The above results support that the use of simulation has improved self-efficacy as well as self confidence in female’s physics learning compared to males. In addition Cavallo, Potter, and Rozman (2004) and Cordova, Sinatra, Jones, Taasoobshirazi, and Lombardi (2014) found a predictive relationship between SE and physics conceptual understanding in higher education. Studies by Zeldin and Pajares (2000) and Sawtelle, Brewe, and Kramer (2012) that evaluated gender SE considered four sources of SE by Bandura (1998) and found that both vicarious learning (VL) as well as social persuasion(SP) source of SE belief influence female students while for male student mastery experience(ME) is the source of SE belief.

According to findings from this research, female students have outperformed their male counterparts in the SE subscale. This might be attributed to VL since, by working in groups, students watched their partners performing task like the one’s they considered their own performance. In addition, the results are indicative of females score higher than males in ME than for VL source of SE subscales. Through the lens of Bandura (1997) the findings predicts ME to be most influential than VL source of SE for female student in physics learning. Among contributing factors is the inquiry-based instruction with simulation that enabled students to interact socially (Fan, 2015). The context of social interaction where these females experienced inadequacy or instability of their current belief has a contribution to these results.

CONCLUSION

Although most research have shown ME source of SE belief for males than females, preliminary results from the secondary school in Tanzanian context predicts source of SE belief for female than male students. This may need further attention. Results are indicative that computer simulation as an instructional strategy provides opportunity for female than male students to develop SE belief in science learning and physics. Finally, it is indicative that computer simulation has the potential to engage students, especially females, and predicts SE to contribute to conceptual understanding of their physical world.

REFERENCES


ABSTRACT

What if you teach high school students to learn mathematical theory of Cartesian plotting and graphing within the context of Art and Design? How is this playful and fearless, demonstrating curiosity and purpose? (Wagner, 2012). How do we label this learning? We call this STEAM at its trans-disciplinary zenith. It is possibility with a capital P. Mixed methods research was employed via participatory observation to gather qualitative and quantitative data related to secondary school learning experience using the parabolic curve as the primary point of departure for student creation of three-dimensional aesthetic objects. The objects themselves relate to the concept of vessel; a container, a receptacle, a holder of something. Documenting the inter-disciplinary approach resulted in an exploration of the complexities we employ to discover meaning in a range of contexts not especially reliant on singular language. Convergence is presented in that mathematical rules unite with the rules of art and design in the attempt to project new concepts into situations where a space for originality exists. Here, the students have been encouraged to imagine new, effective ways of bringing ideas to form (Richmond, 2009). Naturally, developing explicit appreciation/action situations required critical and creative thinking to coincide with lateral and literal approaches to gaining knowledge and understanding of aesthetics. The study presents a reflexive account of the delivery of coursework entitled The Possibilities of the Parabola, from concept to completion.

Keywords: STEM, STEAM, trans-disciplinary, inter-disciplinary, cross-curricular

INTRODUCTION

What if?

Teachers working in cross-curricular STEAM settings often observe magical breakthrough moments where learning thresholds are crossed and boundaries smashed. This study aimed to explore the possibility of gaining an aesthetic experience via engagement in a secondary school STEAM setting.

When you investigate STEM concepts through an Arts context, connections between the knowledge areas might be exposed more explicitly. It seems that Art and Science have been interrelated since humans started thinking conceptually but more broadly, the Arts in the context of STEAM represent Humanities, Languages, Dance & physical movement, Drama, Music, Visual Arts, Media and Design. Embedding the Arts in Science, Technology, Engineering and Mathematics might provide a gateway to understanding and investigating logical functions and abstract concepts more readily. We know this. People like Da Vinci have already shown us. Therefore, it would be beneficial to discuss and confirm exactly what STEM means? Is it a simply an emergent noun in our vernacular? How does the acronym
really represent and affect learning and teaching? Why have we combined four knowledge areas into one acronym? Is the inclusion of A to make STEAM indicative of the interconnected nature of knowledge or simply learning and knowing stuff? Many educators consider STEM to be unequivocal inquiry based learning and including the A in particular, shunts the context into problem-based learning, where the job preparation setting “deploys pedagogy that encourages students to be curious, experiment, and take risks – key dispositions artist habits of mind engender” (Housen, 2002, p. 46). Perhaps the A permits both learner and educator to ask “what if” more often.

Possibility

STEAM is all about possibility. It’s about “problem finding AND problem solving” (Craft, 2015). The Arts provide a way of locating, investigating and synthesising information that might make Science, Maths and Engineering problems more relevant to the life experiences of the individuals that we teach, in their current and future worlds.

STEAM is a way of translating abstract concepts into something concrete. Science is inherently creative and that creativity can easily be made visible. Some would say it’s much harder to connect Maths with creativity but that’s where possibilities abound. The “what if” question that underpins STEAM projects help learners to use their imagination to solve problems; risk and creativity are by-products of engaging the imagination. Given that Gonski 2.0 (Gonski et al., 2018) refers to “creativity” two times in the recent Review to Achieve Educational Excellence in Australian Schools (2018), preferring to fuse “creative thinking” with “critical thinking” in more than eight mentions within the document, it would be fair to state that all inquiry and problem based methods of learning require creativity and criticality.

Incorporating intercultural capacity-building strategies (Wade-Leeuwen, 2016) as well as harnessing the power of visual and creative arts as contributors to understanding STEM concepts upholds the view of hands-on, experiential and imaginative learning being paramount to the acquisition and retention of knowledge. The “what if?” is not dependent on the purchase of STEAM specific furniture or even classroom design, it is more dependent on the imagination, drive and curiosity of the teachers asking the STEAM questions alongside their students.

Teachers must now be branded as bricoleur (Campbell, 2018), with our continuous professional evolution driven by curiosity. Teacher agency, therefore may be currently “conceived as being disruptive, inquiring, intellectually demanding and powerful” (Campbell, 2018, pp. 5, cites Buchanan, 2015; Robinson, 2010). This leads us back to the driving question of “what if you ask a bunch of high school students to learn the theory of Cartesian plotting and graphing within the context of Art and Design?” PoP aimed to place theoretical and material explorations across learning disciplines. We aimed to support an integrative model for the new work order where not only STEM but Arts related practices develop critical and creative thinking tendencies.

LITERATURE REVIEW

The Arts in STEM

Fostering creativity

It is possible to believe that students grow to recognise the way mathematics intersects with creativity when they are given the freedom to explore the points of intersection more directly and playfully. According to Soh (2017) to say we need creativity in education is a cliché because fostering creativity is inherent to the act of teaching. Thus the question is; how does student creativity emerge such that the process and product of learning combine to
provide an aesthetic experience, a situation where all senses are operating at their peak? (Csikszentmihalyi, 1996).

As far back as late last century, we have been trying to address the issue of connecting learning with creativity. Soh (2017) cites the widely referenced paper *Fostering Creativity in the Classroom: General Principles based on extensive review of relevant articles*, by Arthur J. Cropley (1995) in which he lists nine conditions that need to prevail if teachers are to foster student creativity. Summarising Cropley’s (1995) list, these interacting teachers habitually encourage independence; operationalise cooperation and integration; motivate for divergent thinking; delay judgement; encourage flexibility; promote self-evaluation; consider suggestions seriously; provide differentiation of materials and spaces; and manage failure and frustration in order to promote fearlessness (Cropley (1995) as cited in Soh, 2017). How is it that we are still asking for the same in the current education climate?

Traditional modes of education may be disrupted by fully integrating content in ways that are imaginative, challenging and relate to real-world concepts. “The critical engine of [economic] growth is a workforce equipped with STEM skills and knowledge” (Finkel, 2016, p.4). Consistent with this statement, the National STEM Schools Strategy claims that building STEM capacity is essential to the development and support of innovation and productivity regardless of occupation or industry (Education Council, 2015). Both reports agree, “our best future is a future that builds on technology, innovation, ideas and imagination” (Finkel, 2016, p.iv). STEM literacy is increasingly becoming part of the core capabilities that Australian employers need (Education Council, 2015, p.4). Thus, the journey into STEM promotion begins when we open our children’s eyes to the possibilities of science, technology, engineering and mathematics. Often, the gateway to this path can be found in the Arts.

Dislodging mindsets

An aesthetic experience in an education context must be motivated by stimulating action, exploration, awareness and surprise for it to be worthwhile and evocative (Eisner, 1985). As such, the element of surprise was something new to our students. They were more familiar with the idea of learning being a somewhat segregated experience, related to grades and ranks. “Nations that enjoy high international testing outcomes as well as strong STEM agendas have well-developed curricula that concentrate on 21st century skills including inquiry processes, problem-solving, critical thinking, creativity, and innovation as well as a strong focus on disciplinary knowledge” (English, 2016, p. 3, cites Gainsburg, 2016; Freeman, Marginson, & Tytler, 2015; P21, 2002).

Both the zeitgeist acronyms STEM and STEAM are revealing the need to nurture interdisciplinary connections and encourage profound conceptual understandings. Emotions and deep thinking are also key players in the mix (Rahm, 2016), especially if we are aiming to dislodge fixed mindsets (Dweck, 2008). Research in the area of teaching maths through liberal arts, provide findings that display an improvement in student attitudes towards mathematics and its relevance to their lives in general, when mathematical themes are explored through abstract artistic creation (Stylianou & Grzegorczyk, 2007).

Conceptual gateway experiences may result in irreversible learning (Meyer & Turner, 2006). Similarly, the role of constraints, according to Audigé (2017), advocate of Systematic Inventive Thinking (SIT), is to challenge cognitive, relational and structural fixedness in order to enhance multifunctional development. Audigé calls this thinking *inside the box*, proposing that more efficient innovation occurs when working inside the *closed world* of the problem (Audigé, 2017). McAullife (2016) points to reality in that “STEAM is indeed cross-curricular collaboration, but those involved in designing STEAM units, subjects and activities
must be truly multidisciplinary in their thinking, approach and knowledge, and those from each specialisation must be willing to co-coordinate, co-plan and co-teach” (p. 8). In PoP, the intention was work with the material resources we had at hand and theoretical content derived from the expert personnel extant within close proximity.

**RESEARCH DESIGN**

The role as teacher/researcher was included as meta-story in the research design, inescapably reflexive (Figure 1). The study was conducted using mixed methods, during a period of teaching spanning three years and involving 100 student participants.

As immersion requires relationships to be established and nurtured, the autobiographical research genre of Autoethnography “displays multiple layers of consciousness, connecting the personal to the cultural” (Ellis & Bochner, 2000, p. 737), featuring concrete action and self-reflection appearing as “relational and institutional stories affected by history, social structure and culture… dialectically revealed through action, feeling, thought, and language” (p. 737).

![Figure 1. Diagnosis of Methodology Model and Research Design](image)

Action learning perspectives aligned with data collection and analysis methods were implemented to take into account the intellectual capacity of student learning while simultaneously tracking the experience of the *curve to creation* journey. Thus validating the inherent nature of the work (Figure 2).

Schön (2006) illustrates differentiation in the teacher’s professional landscape as topology (as cited in Whitehead, 2006) referring to practitioners “as competent professionals whose practical knowledge is key to developing human capabilities, their own and other people’s” (Whitehead, 2006, p. 46). Thus, this study had a twofold aim: to develop my own and students’ capabilities.

Arts-Informed inquiry is addressed in the methodology because artefacts were produced within the body of this study. Arts-Informed inquiry acknowledges findings being presented beyond the academy. The artefacts produced within the study were critically analysed and assessed in the program of learning. They were also subject to external scrutiny via physical and virtual exhibition. Arts informed enquiry maximises this communicative potential. However, I did not intend to lose my purpose, as teacher, in the exploration. My presence as teacher/researcher remained transparent and apparent and speaks to “the intersection of a researcher’s life with that of those researched” (Ellis & Bochner, 2000, p. 737).
RESULTS AND DISCUSSION

Curve to creation

After our initial research related to applications of the parabola in industrial settings, student investigated the table of values and started physically plotting the curve by hand before moving into digital experiments (Figure 3). Two dimensional experiments not only required an understanding of numeric values used to create the parabolic curve but also how the elements and principles of design can be applied to create interesting patterns and shapes.

Figure 3. Hand drawing using purpose built parabola templates, students plotting, graphing and manipulating the parabola, manually and digitally

Figure 4 shows the way in which one curve can be iterated to create an elegant shape (reminiscent of Spirograph hypocycloids, using vector graphic software). Before launching
into designing and making the 3D items, several design considerations were necessary. These decisions were directly related to the selection of curve, material choice, colour and texture in addition to design constraints outlined in the original brief, specifically the restriction of the use of adhesives in the construction process. Many of the 2D visual designs were applied as a decorative embellishment on the 3D vessel surfaces (see in Figure 5).

Dimensional accuracy of intersecting components required fractional millimetre iterations in the testing stage of the process in order to provide tension and strength in the final vessel form. Cutting and engraving took place within a single use digital fabrication technique. Figure 6 shows an early experiment exploring how to form a shape around a single parabola. In this instance, the line indicates the cutting path.

The same shape is also visible as the solid area shown in Figure 6a, rotated for horizontal stability. Application of iterative rotated parabolas engraved on the surface of the material reference the decorative potential of the curve (see Figure 7).

Figure 4. Intaglio print depicting $y = x^2$  
Figure 5. Surface embellishment using $y = x^2$

Figure 6. Parabola shape  
Figure 6a. Engrave and cut lines  
Figure 7. Realized vessel experiment.

Figure 8. Curving the bamboo ply by reduction technique.
As PoP evolved, we experimented with alternative ways of honouring the parabola in our vessel designs, such as applying reductive techniques: removing internal sections of the material in order to reduce rigidity, allowing stiffness to curve (Figure 8) while maintaining themes of beauty, symmetry, iteration and elegance (Figure 9).

Figure 9. Student vessel designs        Figure 10. Sections of the parabola

Figure 10 displays works created using a section of the parabola, held fast by tension or restriction in the form of wire, fabricated fasteners or rods. It is more difficult to categorise the curve as parabolic yet the aesthetic criteria are still addressed in the pleasing design.

Emerging STEAM technologies led us to experiment with more conceptual parametric modelling software to communicate the idea of vessel using 3D printing (Figure 11). Transferable applications of these designs to real-world structures were discussed and some students went on to use these ideas in senior engineering/design projects. This part of our learning was experimental and the range of designs produced was surprisingly varied. There was solidity as well as weightlessness in the work, with the parabola reasonably recognisable.

Figure 11. 3D printed parabola designs

A helpful relationship
Learning was assessed and analysed by detailed pre and post student questionnaires as well as audience feedback, post exhibition. Students discussed levels of engagement in maths activities as well as the changes in pre and post understanding of terminology such as elegance, specifically the way this term can be applied to both mathematics and art/design.

Around 75% of students gained a better understanding of aesthetics and about a third of those could describe the immersion in the PoP project as an aesthetic experience in itself. Comments about the relationship between math and art/design propose it “is a helping relationship, where one assists the other” and, “the PoP course has been a stepping stone into my future math(s) courses on parabolas”. Frequently occurring adjectives within the audience
feedback include “sophisticated, elegant and intelligent”. Observers were able to identify the parabolic curve inherent in the designs and most agreed that the students were successful in their attempts to demonstrate how mathematics can be beautiful (see Figures 7, 8, 9 and 10).

CONCLUSION

Understandably, using the parabola for inspiration to drive the explorations through two and three dimensional art/design projects was a totally new experience for all of us. The risk we took as educators was to promote and encourage the idea that participants in STEAM learning might begin to identify themselves as trans/inter disciplinarians in a world led by both convergent and divergent experiences.

The material form and function explorations revealed hidden metaphor, ensconced with narratives possessing the potential to cross a myriad of curriculum boundaries. The learning never lost sight of the parabola and its relationship to mathematics. It also significantly embedded knowledge and understanding of this elegant curve into the heart of the Arts. The goal was to encourage students to make a connection between Maths and the Arts in a unique and positive way in order to augment their educational experiences.

Repeated use of mathematical terminology seamlessly integrated new words with the language of art and design. Students became familiar with the variables that make the parabola “fatter” or “thinner”, identifying and visually articulating this through their vessel designs as well as through manipulation of the metrics within mathematical functions and equations. If we are to model communities of best practice, then we must be committed to exhibiting and engaging in collaborative knowledge building, sharing and delivery activities that are necessarily team devised and collaboratively taught. Ultimately, we want young learners to gain an understanding of mathematics in novel ways and perhaps release them from the general view held by many that the study of maths is not related to a positive aesthetic experience but rather a bolster to strong self-efficacy and self-confidence.

REFERENCES


SHIFTING AND SHAPING STUDENT STEM BELIEFS: LEARNING FROM A TRANSDISCIPLINARY ROBOT PROJECT

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ABSTRACT
This paper reports on a transdisciplinary STEM project in one UK secondary school. Over ten months, a team of upper secondary students designed and constructed several heavy weight robots that were tested and refined in cycle of ‘real life’ competitive battles. The projects, which involved constructing electro-mechanical non-autonomous robots, demanded students contend with engineering processes and technical skills while drawing on their collective mathematical and scientific knowledge. While much has been written about teacher belief and practices for STEM learning, less is known about student beliefs and their experiences as STEM learners. With concerns about student participation in STEM study and meeting future workplace demands for STEM related careers, this study aims to investigate the factors influencing the STEM beliefs and values of school students involved in STEM activities. In-depth interviews with 12 students from Year 10 to 13 and observations in the school workshop elicited student beliefs and practices for STEM. The emerging findings revealed: shifting perceptions of STEM throughout project experiences; the influence of project experiences for shaping subject and HE course choices; and reciprocal connections between STEM projects and individual subject study. The findings also highlight the active cognitive processes aligned with engineering ‘habits of mind’ including: systems thinking; visualising; creativity; learning from mistakes; and problem solving. The findings of this qualitative research seek to assist teachers and educators to better understand how STEM experiences influence students STEM beliefs, subject choices, career aspirations, academic study, and future engagement in STEM related activities.

Keywords: Student STEM beliefs, transdisciplinary projects, electro-mechanical robots, engineering

INTRODUCTION

Science, technology, engineering and mathematics or STEM, refers to distinct but complementary approaches to knowledge, skills and processes in related fields. Whilst each discipline is critical, in combination they enable a different approach to inquiry and provide platforms for applying concepts to solve problems and other activities.

Recently, the dominance of science and relative absence of mathematics and engineering in discussions about STEM perspectives has led to researchers and other stakeholders calling for more equitable representations of all STEM disciplines (English, 2016; Honey, Pearson, & Schweingruber, 2014). It is argued that understanding the effectiveness of integrated STEM education is important for developing students’ knowledge
of core content material and to reflect a balanced distribution of student achievement across all STEM subjects (English, 2016).

A STEM approach to learning is seen as valuable because it “removes the traditional barriers separating the four disciplines and integrates them into real-world, rigorous, relevant learning experiences for students” (Vasquez, 2015). It is generally acknowledged that promoting STEM education through inter-disciplinary projects is effective for fostering creative problem solving, enhancing student engagement and situates mathematics and science problems in contexts that students consider ‘real’ (Ziaeefard, Miller, Rastgaar, & Mahmoudian, 2017).

The importance of STEM education is reflected in coherent STEM education implementation plans in several countries for example: the STEM Education Implementation Plan 2017-19 in Ireland (Department of Education and Skills, 2017); and the Science, Technology, Engineering and Mathematics: Australia’s Future report (Office of the Chief Scientist [OCS], 2014). These plans are welcome however, the persistence of relatively low participation in mathematics and science in upper secondary schools suggest a need to more clearly understand factors that underlie student beliefs and values for STEM study and those that may impede future participation.

This study reports the activities of a school robot team in one Secondary School in the UK. The school Robot Team was formed when the students designed and built their first electro-mechanical robot. Subsequently, the students built four more robots for national and international competitions. The robot projects were established as a non-curriculum activity and the students in the Robot Team met after school several times a week during term time, on the weekends and in school holidays to meet competition deadlines. The robot project is an example of transdisciplinary STEM learning experience, integrating all four STEM areas, it draws on engineering type ‘habits of mind’ and simulates a project based learning setting.

This study therefore poses an opportunity for investigating student STEM beliefs and practices and cognitive processes within an integrated project. The research questions addressed by the study were:

1. Investigate student beliefs about robot building, their study of STEM subjects and career aspirations.
2. Develop an understanding of the type learning processes and habits of mind promoted through integrated STEM projects

LITERATURE REVIEW

STEM landscape in the UK

The encouragement of STEM subject uptake and career pathways has increased over the last decade driven by concerns about the declines in participation and expected shortfalls of filling technical and professional roles such as in engineering (Morgan & Kirby, 2016) and science (Archer et al, 2016). These concerns are amplified by expected future demands for skilled STEM employees in this expanding sector and to replace those who are expected to retire or leave the profession.

In the UK, STEM related learning is associated with the disciplines of science, mathematics, design and technology, and computer science that are guided by relevant curriculum documents at both GCSE and A level (Department for Education [DfE], 2014). The type of STEM activities available to school students are variable with some schools promoting STEM events connecting with STEM organisations and offering extra curricula STEM clubs (e.g. robotics, science and mathematics clubs). The provision of many STEM
related activities occur as extra-curriculum events, yet there is little research about the pedagogical foundations underpinning these STEM activities. Therefore, investigating the value of such activities for supporting educational outcomes is warranted.

**Robot activities in schools**

In recent years there has been a general increase in robotic type activities in school settings (Danahy et al, 2014; Liu, Newsom, Schunn, & Shopp, 2013) mainly through the availability of manufactured robot kits. Commercial robot kits such as FIRST LEGO League, VEX Robotics systems and other versions typically include pre-made components and include detailed instructions for assembly (although LEGO Tech Challenge and Robotics are less prescriptive) and controlling the robot is usually via programmed instructions linked to specialised software.

Pre-made kits are popular in schools because they can be assembled relatively quickly, do not require specialised equipment, instructors do not need to possess technical knowledge or use particular instructional approaches for projects to be successfully completed. Robotic kits can therefore provide a convenient, relatively accessible and interesting robotic experience, however less sophisticated kits offer limited cognitive challenges for students in terms of learning from processes such as planning, creativity and solving problems.

**Electro-Mechanical Robot Building**

The scale and purpose of building heavyweight (110kg) electro-mechanical fighting robots makes them distinctly different from robotic kit experiences for students and are more similar to engineering projects. Each robot is designed with a specific purpose, with most components requiring bespoke manufacture or adaptation from pre-made parts. Further, because there are no instructions the students need to work collaboratively to make decisions about design and construction (what, how and when) to bring the build together.

Ultimately, the robots need to comply with the rules of the competition organisers; however, the robot design is mainly open ended with the only constraints pertaining to size and weight (and safety requirements). In terms of construction, building a heavy electro-mechanical robot poses two distinct challenges: how to make the robot move; and how to build the robot so that it can both attack and defend itself when tested against competitor robots in ‘live’ battles. There are five main phases for constructing electro-mechanical robots including:

1. Design (chassis, weapons, internal systems, including CAD)
2. Manufacture (chassis, sourcing and adapting internal components)
3. Construction (chassis and systems)
4. Trialling (operational)
5. Testing (in competition against other robots).

Throughout each phase the students draw upon knowledge and skills across a range of subject areas including mathematics, physics, chemistry, design and technology, and computer science. The builds also provide students with opportunities to learn new technical skills (e.g. welding, drilling), using appropriate machinery (e.g. lathes and saws) and working with different materials (e.g. hardox, armox and HDPE).

They area also required to design, create and connect various systems (e.g. mechanical and electrical). Apart from skill development, robot building demands a host of higher order thinking processes such as visualising; improving; adapting; problem seeking; and creative problem solving. It also requires systems thinking, which is the ability to see problems or situations holistically from multiple perspectives and understand the relationship and
connections between these systems the Engineering Habits of Mind (EHoM) framework (Royal Academy of Engineers [RAE], 2017).

**RESEARCH DESIGN**

This small-scale qualitative study included 12 student members of the school Robot Team who volunteered to take part in one to one interviews and to be observed while working when building robots. At the time of interview, the students had been involved in building robots for nine months and were between their fourth and fifth build. Table 1 provides details of the year group, gender, A-level choices/intentions (one student was taking the International Baccalaureate Diploma) and HE course and career aspirations of participants at the time of data collection.

<table>
<thead>
<tr>
<th>Year &amp; Gender</th>
<th>Code</th>
<th>A-level choices (year 12 &amp; 13)</th>
<th>Intended choices (years 10 &amp; 11)</th>
<th>HE/ career aspirations</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 F</td>
<td>13F1</td>
<td>M (mech)* Physics, Resistant Materials</td>
<td></td>
<td>Architecture</td>
</tr>
<tr>
<td>13M</td>
<td>13M1</td>
<td>IBD (Chemistry, English, Physics, Maths, Mandarin, classics)</td>
<td>Civil Engineering</td>
<td></td>
</tr>
<tr>
<td>12 F</td>
<td>12F1</td>
<td>Biology, Chemistry, Maths, Further Maths</td>
<td>Veterinary Science</td>
<td></td>
</tr>
<tr>
<td>12 F</td>
<td>12F2</td>
<td>Product Design, Art, Geography</td>
<td>Art</td>
<td></td>
</tr>
<tr>
<td>12 F</td>
<td>12F3</td>
<td>M (mech) Physics, Product Design</td>
<td>Design Engineering</td>
<td></td>
</tr>
<tr>
<td>12 M</td>
<td>12M1</td>
<td>M (mech) Physics, Product Design</td>
<td>Design Engineering</td>
<td></td>
</tr>
<tr>
<td>12 M</td>
<td>12M2</td>
<td>M (mech) Physics, Chemistry</td>
<td>Aeronautical Engineering</td>
<td></td>
</tr>
<tr>
<td>12 M</td>
<td>12M3</td>
<td>M (mech) Physics, Resistant Materials</td>
<td>Aeronautical Engineering</td>
<td></td>
</tr>
<tr>
<td>11F</td>
<td>11F1</td>
<td>Product Design, Mathematics, Physics</td>
<td>Engineering (automotive)</td>
<td></td>
</tr>
<tr>
<td>11M</td>
<td>11M1</td>
<td>Product Design, Computing, Business Studies</td>
<td>Engineering (automotive)</td>
<td></td>
</tr>
<tr>
<td>10F</td>
<td>10F1</td>
<td>Mathematics, Physics, Art</td>
<td>Architecture</td>
<td></td>
</tr>
<tr>
<td>10F</td>
<td>10F2</td>
<td>Mathematics, Biology, Product Design</td>
<td>Bio-engineering</td>
<td></td>
</tr>
</tbody>
</table>

*M (mech) = A level Mathematics (mechanics modules)*

The interviews took place in the school design and technology workshops and lasted between 35-45 minutes. The interviews were audio-recorded and later transcribed for subsequent analysis. The interview questions were asked in clusters, two of which are relevant to the aims outlined in this paper. The first cluster of questions asked about STEM beliefs and connections, for example asking: “Where do you perceived the science, technology, engineering and mathematics evident in the robot builds?” and “Can you recall connections between what you have learnt in class and building the robots?”

A second cluster asked about various thinking processes that students recalled using when building the robots, for example: “How did you go about building the robot, in term of visualising?” and “Can you describe problems you encountered?” The first cluster of questions were analysed inductively and coded to emerging themes. The second cluster was coded according to the six aspects of the EHoM framework (RAE, 2017).

**RESULTS AND DISCUSSION**

It will be recalled that the aims of this study is to investigate the factors influencing the STEM beliefs and values of school students involved in STEM activities and to report the students use of cognitive processes aligned with engineering ‘habits of mind’. A full analysis of the data collected is on-going therefore initial findings are reported here.
The first research question aimed to elicit student beliefs about robot building in terms of their study of STEM subjects within the formal school curriculum. Further, student views about the application of these subjects when building robots were sought and if their involvement in robot building influenced their aspirations. The findings are reported under the following four subheadings.

**Student beliefs about individual STEM subjects**
Variations in student beliefs were reported. For example, the location of mathematics and science were more similarly perceived but described differently by the students. Further, technology and engineering were not perceived in the same way as some students focused on technical processes as part of the building (e.g. machinery used to make parts) and others as operating/controlling the robot (e.g. programming speed controllers).

Several students perceived strong ‘crossovers’ or links between all STEM areas, for example:

*It really does cross over, technology in general, designing the robot…so I am learning new CAD programmes like Solid Works…and then I learn about machinery which is important if I was going into the product design world…maths comes into it like if you are working out the speed of the blades (12M1)* and another said: *I think the whole point of STEM is that it’s one word isn’t it? It’s supposed to be all those subjects put together but it’s still like very much separated within itself”*(12F3).

**Shifting perceptions of STEM**
Students reported shifting dominance of subjects within robot builds suggesting that mathematics and science were more evident during the design phase and less so during the later phases. For example: *They’re definitely dominant at different times, because at the start engineering has almost nothing to do with it, because we’re not thinking how we are going to build it…at the start it’s more technology and mathematics (13M1)*

**Shaping thinking about choices**
Several students reported that their building robot building experiences had shaped their thinking about subject and HE courses. *I feel I want to do robot things…that’s what I want…to make an object that works instead of Civil [engineering]…like buildings and things (11F1).* In other cases it changed choices: *I was definitely deciding between doing a degree in pure physics…and doing Robot Wars obviously made me more, it showed me a more hands on side of engineering…(12M2)*

**Reciprocity between robot building and academic subjects**
Reciprocal benefits of working with robots and making connections to academic/class study were reported, for example: *We worked out the weapon with the centrifugal force…and we worked out how each weapon would fly out based on the things we had done in physics (13M1)* and *It brings a lot of the concepts we study to life…with the robot you get to see it all applied…the limits that are applied (12M3).* Another student reported, *When I am looking at mechanics in maths…and then I look at the robot, I think that has an effect on the robot the same way that the robot has an effect on my math’s (12F3)*
Findings addressing the second research aim are guided by the six aspects identified by the EHoM framework (RAE, 2017) and include: systems thinking; adapting; problem solving; creative problem solving; visualising; and improving.

**Systems thinking**

The student reported thinking holistically about combining multiple systems when robot building:

> It’s like a series of systems...the whole process...design is a huge part of it...how your robot differs from everyone else...Then you have to think of all the things within that...engineering how your design will work so you are changing your design based off your engineering limits...and that can move into physics looking at the stress and strain in the material, and then you are also designing the electronics and how that will fit in (12F3)

**Adapting**

The students reported that being flexible and learning from mistakes were important learning experiences, for example: Obviously at the start...we had to create a robot completely from scratch, but now [we] have built more and we know the design flaws and what works well (12M1) and I think the most valuable thing is getting it wrong...because that’s the best way of learning is to get something wrong ... and find out why it was wrong so you can do it better but know why the next thing is better (13F1)

**Problem seeking and solving**

The students reported this element promoted logic and reasoning: I think the problem solving aspects and logical thinking...is important for building a robot because you need to be able to say...what’s happening here? This is not working so what do I need to do about that...the logical thinking is important (12M1) and I didn’t realise how much problem solving there was...because when you put it in and it breaks there is nothing to tell what is actually broken (10F2)

> The biggest problem was the wedge on top for the weapon. We realised that it was too flat and so when the weapon was down it was hitting on the floor...and because the weapon wasn’t working, we couldn’t control it to pull it up basically...which was a major issue really, because you can’t drive, you can’t do anything... (12F3)

**Visualising and abstracting**

Being able to imagine how the various systems and components would work was seen as essential: I think it’s really quite important to be able to imagine what’s going to happen, to be able to visualise what the scenario might be...in a battle you don’t know what’s going to happen, you don’t know what could go wrong, you don’t know the effect of different robots and different weapons. It’s quite helpful to talk it through (12F1)

**Improving**

Students reported learning from past experiences and appreciated the importance of testing the robot in ‘real-life’ battle situations. In previous robot battles the students had seen the consequences of not protecting batteries from potential damage and also found that in time pressured situations (e.g. between battles) that the batteries and electric systems need to
be easily accessible for repair: *Our first robot had issues with the batteries being near the outside... so now we put the batteries closer in, we put the motors in a way that let’s us get to them...*(12F1)

Other benefits include the process of being able to develop a machine that could physically be used, for example: *The fact that you’re completing an actual project. It’s not on a computer screen ... it’s actually there. You will get a final product out of it. You can actually use it and control it. You find all these core components and yeah bring them together and that’s quite pleasing at the end of it* (12M2).

Another student commented on the long term engagement of being a robot builder, for example: *I think it’s engaging because it’s unpredictable and it’s never finished, so you can never build the perfect robot that will win every single fight, so there’s always something that you can come back and add to the robot or there’s always a better way of doing something that you’re already doing and so I think that shows because I’m always coming back for more and coming back, there’s always ideas ticking over in my mind of how we can improve things* (12F3).

CONCLUSION

This small-scale study elicited rich data about how students perceive STEM subjects within a transdisciplinary project. It revealed that students hold variable beliefs about STEM in integrated projects with some clearly identifying individual STEM disciplines and others reporting more holistic views. Several students also reported ‘shifting’ rather than static notions of STEM disciplines in the robot projects, with mathematics and science being more obvious in the early phases of robot building with technology and engineering more dominant in later phases.

These findings offer a different way of viewing the nature of STEM in integrated projects particularly in light of research that is concerned about dominance of science in STEM education, the so-called ‘servant’ role of mathematics and inequitable representations of STEM disciplines.

The findings also highlight that the nature of long-term projects place demands on student thinking over time and under varying circumstances. Not only were the students required to think about different systems and how to connect these, they were also challenged to be creative and to seek out and solve problems in each phase of robot building.

In this case of robot building, students with various ‘academic’ backgrounds and interests were brought together with a central purpose that allowed students to apply their knowledge and their ‘hands on’ skills were enhanced. Additionally, collaboration was essential in the school workshop and at competitions as they aimed to ‘improve’ their robots. Their persistence was evident as they moved through a series of iterative processes within each and between different robot builds. At a time where student interest and participation in STEM education is of public concern, these types of transdisciplinary robot projects provide opportunities to make explicit links to discipline knowledge, promote cognitive challenge, team work, and engagement.
REFERENCES


REAL WORLD EDUCATION: NEW ROUTES TO STEM GRADUATE CAREERS

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ABSTRACT

As taught in universities, STEM disciplines are closely aligned with industry and involve both theory and application. To combat perceived skills gaps amongst graduates, degree apprenticeships have been introduced in the UK. The student is an apprentice, working for a company while attending university, for example, one day a week, to achieve a degree. A significant component of the degree is work-based learning, application of learning directly in the workplace. The benefits to employers include the chance for work-integrated, degree-level training for their employees. The benefits to apprentices, compared with traditional on-campus study, are the salary and relevant work experience while studying. What is less clear is whether these benefits are the motivations behind choosing this mode of study over on-campus study. To gain a deeper understanding of this model for STEM education, computing apprentices were asked about their expectations, hopes and fears, through a short, individual survey and a group drawing exercise. These were compared with responses from on-campus students. Both cohorts shared the goal of a well-paid job and were anxious about succeeding with university study. The apprentices were concerned about balancing work and study, while the on-campus students were more concerned about student debt.

Keywords: Graduate career, work experience, placements, employers, graduates, computing

INTRODUCTION

In 2014, the UK Government introduced Degree Apprenticeships—work-based learning degrees offered by selected universities in England. The Scottish Government followed in 2017 with Graduate Apprenticeships (GAs). The GA student is a full-time employee, studying towards their degree through day-release, block release or distance learning. For GA degrees, a strong tri-partite relationship is formed between the university, the employer and the student, similar to that in US models of Co-operative Education or the German Dual system.

However, unlike (for example) the US Co-op model, the GA student is employed by only one employer throughout (and theoretically beyond) their programme of study, and maintains their status as employee at every stage. GA programme designs are required to draw upon practical work undertaken by the apprentices in their workplaces, and recognise this through academic credit. In this way the degrees can be accelerated, compared with a part-time student working in a sector unrelated to their course.

The first such degree frameworks in Scotland were for STEM subjects including computer science and engineering. Generic frameworks were published for Software Development, Information Technology for Management and Business and Cyber Security.
Universities were invited to request funded places. Once awarded, universities then approached industry to recruit apprentices.

The distinctiveness of GA degrees is evident in narratives that have been established around the benefits to employers. These are articulated in terms of staff development: an opportunity to invest in staff, through skills development, to enable them to meet high industry standards, while also gaining the immediate benefit of that investment in the form of a skills bonus (Skills Development Scotland, n.d.). This contrasts with the benefits to the employer from more mainstream forms of work-integrated learning (WIL), where employer benefits have primarily been couched in terms of producing graduate ‘work-readiness’ — sets of skills and attributes that enable smooth transition into the workplace and facilitate a quick return on salary investment.

Work-integrated learning as a means of applying theory in practice is well understood for STEM disciplines, however the perspective of students undertaking applied GA programmes has not been investigated widely. This study explored the aspirations, expectations and concerns of the first cohort of GA students at a Scottish university, compared with first year students undertaking traditional on-campus degrees. Through research, insights can be gained into the experience of GA students in order to appropriately support the students themselves, and also to assist universities and employers to successfully navigate the degree apprenticeship model.

THEORETICAL CONTEXT

The literature on motivations to undertake, and expectations of, university study is introduced to frame this comparative study. In terms of reasons for attending university, Cote and Levine (1997) found reasons included the prospect of a good career, as personal development and as a response to parental expectations. Likewise, Balloo, Pauli, and Worrell (2017) surveyed first year students about their reasons for attending university to find that improving career prospects was the most important reason. Improved quality of life and personal development were also cited.

Money, Nixon, Tracy, Ball, and Dinning (2017) found students valuing “having the chance of a new start and the opportunity to build skills and knowledge” (p10). Student expectations of university are shaped by the decision making process behind whether or not to attend university (Kahu, Nelson & Picton, 2016) and also influence (negatively or positively) their subsequent adjustment (Jackson, Pancer, Pratt, & Hunsberger, 2000). Those who approached university study with negative expectations, and with little sense of agency, were more likely to drop out and suffer from depression.

Some students have well-defined beliefs about what to expect, through narratives of experiences of parents and siblings (Baker, 2014). Those first in their family to attend university or undertaking a new type of degree may find imagining a university-self more challenging through a lack of role models and relevant cultural capital (Bourdieu & Passeron, 1990).

There has been considerable research into self-efficacy, belonging and well-being for on-campus students (for example, Kahu Stephens, Leach, & Zepke, 2015; Kahu et al. 2016; Thomas, 2012; Wäschle, Allgaier, Lachner, Fink, & Nückles, 2014). How self-efficacy and belonging affect GA students in the context of their interactions with two distinct loci, workplace and university, is not clear. Self-efficacy may not be uniformly experienced across these two disparate contexts, each of which require distinct (if inter-related) forms of
performance. GA students may predominantly feel a sense of belonging to their workplace rather than the university.

This paper argues that understanding how expectations of university study might differ for GA students compared with on-campus students should be a core concern for universities working with new models for STEM degree-level education.

METHODOLOGY

This study gathered both individual and group perspectives, comprising a short survey (n=42) and a Rich Pictures (RP) exercise (n=42, resulting in 10 RPs). The Rich Picture is a collaborative research method that enables participants to model complex situations, surfacing and exploring events and actions. RP has previously been used to capture student expectations (for example, Berg, Bowen, Smith, & Smith, 2017) (and in many other contexts). The GA students (Cohort A, n=22) and the on-campus students (Cohort B, n=20) were all in their first semester of study. The survey asked for demographic information and about their motivations to undertake their degree.

On completing the survey, participants broke into self-selected groups and were asked to draw a Rich Picture (Cohort A, 5 RPs; Cohort B, 5 RPs) to reflect aims and aspirations; what they hoped they would get out of the degree; what they were worried about. Each group then described their drawing to all participants. These descriptions were audio-recorded and transcribed.

RESULTS AND DISCUSSION

The survey results gave an overview of the demographics of each group and show a similarity between cohorts in terms of parental experience of higher education and gender (Table 1). However there was more diversity in terms of age: the On-campus Cohort were mostly under 21, and all under 25, while the ages of the apprentices varied more widely.

<table>
<thead>
<tr>
<th>Table 1. Participants’ parents’ HE attendance, age and gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAs (Cohort A)</td>
</tr>
<tr>
<td>Both parents attended university</td>
</tr>
<tr>
<td>One did</td>
</tr>
<tr>
<td>Neither did</td>
</tr>
<tr>
<td>Age: under 21</td>
</tr>
<tr>
<td>Age: 22–25</td>
</tr>
<tr>
<td>Age: over 26</td>
</tr>
<tr>
<td>Gender: female</td>
</tr>
<tr>
<td>Gender: male</td>
</tr>
<tr>
<td>Gender: other</td>
</tr>
</tbody>
</table>

The survey asked “What are your main aims in undertaking this [apprenticeship] degree?” The themes to emerge are denoted in Table 2, where the figures indicate the percentage of participants, per cohort, who mentioned this aim.
Table 2. Participants’ reasons for undertaking the degree

<table>
<thead>
<tr>
<th>Reason</th>
<th>GAs (Cohort A)</th>
<th>On-campus (Cohort B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain knowledge and skill</td>
<td>72%</td>
<td>75%</td>
</tr>
<tr>
<td>Improve career/ options</td>
<td>32%</td>
<td>60%</td>
</tr>
<tr>
<td>Gain degree qualification</td>
<td>63%</td>
<td>5%</td>
</tr>
<tr>
<td>Professional/ personal growth</td>
<td>23%</td>
<td>75%</td>
</tr>
<tr>
<td>To continue employment/ gain work experience</td>
<td>23%</td>
<td>0%</td>
</tr>
<tr>
<td>To benefit employer/ organisation</td>
<td>18%</td>
<td>0%</td>
</tr>
</tbody>
</table>

The GA Cohort reported more aims per person (1.9) compared with the On-campus Cohort (1.3) and the aims included two unique to GAs, concerning benefits to their employer and gaining further work experience while studying.

The survey asked “What do you think will be the main challenge(s) for you?” Participants from both groups expressed concerns related to learning and understanding. The GA Cohort anticipated challenges in terms of establishing a balance between work and study, (returning to) the academic environment, and maintaining their job for four years (one of the tenets of their degree). The On-campus Cohort, most of whom had left school in the last year, also mentioned dealing with a change in their circumstances, e.g. “The main challenges are most likely to be living away from home and studying a lot on my own” (survey response, on-campus student).

The RPs, together with the transcripts of the students’ descriptions, were analysed to identify common themes and motifs across the pictures, including themes common to one cohort, but missing or different in the other cohort’s pictures. The main themes to emerge from the RPs are categorised as: the mountain to climb; achieving academic success; the goal of material acquisition. The cohorts diverged when describing the nature of the challenges along the way.

**A mountain to climb**

Study as a perilous struggle or adventure was depicted variously through metaphors of climbing, diving, swamps, snakes, and games (Table 3).

<table>
<thead>
<tr>
<th>GA_RP_3</th>
<th>GA_RP_4</th>
<th>On-campus_RP_1</th>
<th>On-campus_RP_5</th>
</tr>
</thead>
</table>

Both cohorts expressed the metaphor of an academic journey with a similar endpoint; both emphasised specific perils and hazards; both indicated uncertainty around the extent to which future goals were achievable. Realistic student expectations have previously been linked to success (Lehmann, 2012, Jackson et al., 2000), so the depictions of endeavour, beset with uncertainties and challenges, suggests a good level of awareness and realistic expectations.
Keeping up

Concerns about ‘keeping up’ were depicted in three RPs, as shown in Table 4. For the GA Cohort, the pictures depicted the challenges of work/study balance. For the on-campus students this was linked with finding time to sleep and concerns about money. In each case, academic failure was the consequence of not keeping up.

Both cohorts expressed concerns; however, money worries only featured in the on-campus Cohort RPs. The crossing out (in Table 4, On-campus Cohort, RP4) is a form of prohibition icon, used to clearly express something forbidden or inaccessible (Berg et al., 2017). The dollar and pound icons in On-campus Cohort RP5 represent money, depicted as the final destination in their hazardous journey. The steep-sided pool of debt in final year, with an unclear alternative path depicted by the dotted line, icon shows a final barrier to reaching their destination.

Table 4. The concerns: keeping up and money worries

| GA RP 5 | On-campus RP 3 | On-campus RP 4 | On-campus RP 5 |

Most of the on-campus participants were looking for part-time work. Part-time work and its impact on academic success have been explored extensively (for example, McGregor, 2015) and the advantages have also been well documented. In computing, employers have mentioned that any paid employment signals a positive work attitude (Smith & Smith, 2016). For the apprentices, one further instrument at play is the expectation of adding value to their employing organisations. The apprentices, through the survey responses, were observed to hold expectations for themselves, both as individuals and employees. These centred on skills development, including a desire to acquire skills and apply them in the workplace to demonstrate value.

Academic success

Academic success was depicted in terms of graduation, a good degree, and A-grade exam scripts, though this did not seem to be, in itself, the end goal of journeys. Rather, academic success was illustrated as leading to careers and material acquisition. The On-campus Cohort had fewer expressions of graduation, (appearing in 2/5 RPs); indeed the pinnacle was generally seen as acquisition of a job related to their degree. The GA Cohort seemed more assured of a good/specialised job; the requirement to achieving this being to succeed academically.

The positive impact of a good degree has been found elsewhere in studies of student expectations (Berg et al., 2017). In a cross-institutional study of confidence and belonging, Yorke (2016) found male students to be more confident than females, and older students more confident than younger students. In addition to age and gender, class plays its part.

For example, Lehmann’s (2012) study of first-generation students from working-class backgrounds found a “heightened sense of uncertainty and worry” (p. 541) amongst their
participants regarding fitting in or integrating. In his study, holding well-defined and realistic career goals, and chance encounters at university played an important part in their successful completion. It is unclear what the equivalent of a chance encounter might be for apprentices, with fewer opportunities for interacting with academic staff and the wider student body.

**Career as route to wealth**

The end goal of wealth, as exhibited through material acquisitions (house, cars) and expensive holidays, was a common feature in all RPs (Table 5). While this concept is easier to depict than, for example, enjoying rewarding work or serving society, recent research does indicate a movement towards more transactional approaches to work, suggesting changes to work contracts and increasing reliance on freelance and flexible working as drivers for new attitudes to working life (Shaw & Fairhurst, 2008). Lehman (2012) warns about student reliance on instrumental reasons to attend university which can deter students from integrating fully and lead to subsequent feelings of alienation.

**Table 5. Wealth**

| GA RP 1 | GA RP 3 | On-campus RP 3 | On-campus RP 1 |

**CONCLUSION**

The overarching aim of the Scottish Government in funding Graduate Apprenticeships is to align industry requirements for skills with university education. For STEM educators, this involves a shift from encouraging work placements and other forms of work-integrated learning for on-campus students, towards recognising the workplace as a site of learning and bringing student apprentices in from their workplace to experience university study.

This study captured the expectations of this new cohort of graduate apprentices, starting computing degrees. Parallel data collection from on-campus students enabled comparison. The apprentices and on-campus students were similarly concerned about academic failure, and linked academic success with the trappings of wealth. Their pre-occupations about how they would achieve this differed: apprentices were concerned about the challenges of balancing the demands of work and study while on-campus students were concerned about student debt.

The study indicates that graduate apprentices’ perceptions relating to expectations are shaped by their distinct circumstances, reflecting their navigation of two sites for learning and success. A deeper understanding of how apprentices successfully navigate between these sites will inform universities involved in developing new models for work-based learning. The next step for the work is to gather life narratives of the apprentices, through interviews,
to provide in-depth context-rich data relating to their identity construction, early education, work and study decision, experience of work-based learning, and the influence of others.

REFERENCES


ABSTRACT

Incorporating STEM through integrated curriculum presents as a challenge for many secondary schools, partly because teachers may find themselves teaching content that they are not specialised in, that is, teaching out-of-field. Such experiences may present challenges in terms of knowing the content, what teaching approaches are most suitable, how to support students who are having difficulties. Some resources are useful, but research is showing that teachers need more than a textbook and a few handouts to help them feel comfortable with teaching in these new areas. This presentation draws on data from a longitudinal project following teachers new to teaching a subject (principally STEM related subjects) for two or three years. Case studies of the school and vignettes of the teachers are used to describe the experience of teachers learning to teach a new subject, and show how the school context and broader context of the teacher influenced this learning. We illustrate the supports that were used to enable teachers to develop confidence and build capacity. These scaffolds were seen to be strongly linked to whether there is a culture of support, innovation and collaboration within the whole school or amongst teacher teams. Given that STEM can involve teachers working outside their field of expertise, suggestions are provided for how teachers can collaborate to support staff to develop new content and how STEM teachers can develop new ways of working whilst maintaining quality teaching across disciplines.

Keywords: STEM, teaching out-of-field, support, innovation, collaboration

INTRODUCTION

The many versions of STEM emerging within Australian schools are both confusing for schools still trying to work out what STEM is and how to incorporate it, but also freeing as it
can be implemented in a variety of ways. At the heart of discussions are the relationships between the STEM subjects within different STEM models, and how we might distinguish STEM-related learning from non-STEM learning. Whether to integrate subjects, introduce new pedagogies (or new ways of thinking about old pedagogies), and how to focus on student skills and capabilities, are all open to debate when a school chooses to engage with STEM, as is the need for teacher learning to support these changes.

In secondary schools in particular, where there is a move to integrate STEM, teachers are needing to learn to teach content and incorporate modes of inquiry associated with subjects that they are not specialised to teach. This issue of teaching out-of-area, or out-of-field, has been present in Australia for some time, where teachers teach subjects in which they are not specialised, such as a science teacher teaching mathematics. Such teaching assignments can pose problems for teachers who are unfamiliar with the content and ways to teach it. Little is known about how teachers manage the requisite learning processes associated with subject integration or teaching new subjects and the effects of the school context, and how the various dynamics involved change over time.

There is mounting evidence to show that the school culture is critical in determining how teachers cope and manage with teaching out-of-field (du Plessis, Carrol, & Gillies, 2015), that identity plays a role in how teachers respond to this challenge (Bosse & Törner, 2015; Hobbs, 2013), and that support mechanisms with which the teacher can be provided, or seek out and construct for themselves (Hobbs, 2013), are crucial.

GOALS AND OBJECTIVES

This presentation draws on data from a qualitative longitudinal study examining the learning teachers undertake when teaching new subjects. A goal of the research is to examine the changing landscape of school and teacher practices over a three-year period, exploring the support and professional learning of out-of-field teachers. This paper will report on data relevant to one of the three research questions from the larger study:

What school practices successfully support the development of teacher knowledge, identity and practice during boundary crossings between specialisations?

THEORETICAL FRAMEWORK

Discussion around teaching out-of-field has tended to focus on a “Deficit Position”, given that out-of-field teachers can feel stressed, unprepared and can struggle to produce quality learning outcomes for their students (eg. Coetzer & Coetzee 2015; Pillay, Goddard, & Wilss, 2005; Schueler et al., 2016). Du Plessis (2013) points out that it is not necessarily having to teach out-of-field that is the problem, but the poor support that some teachers experience stemming from a lack of understanding by school leaders. When considering that this is essentially a whole school issue, Taylor (2000) also noted the additional strain that out-of-field teaching can place on mentors, heads of department and others who are called on to support the teacher.

These deficit images don’t always ring true for teachers on the ground. While teachers can feel forced to learn new content and teaching approaches, and can need to rethink how they see themselves as teachers, some teachers see this as an opportunity for professional development and identity expansion. This “Opportunity Position” is reflected in Selvakumaran (in prep), where the author, a teacher from a high school in New South Wales, taught out-of-field early in her career and now leads the school in a whole-school initiative.
researching subject-related ways of knowing, doing and being that are essential for teachers to understand as they learn to teach out-of-field:

Working collaboratively, the HSIE team has evidence that it has strengthened teacher identities, better understood general instructional and subject-specific pedagogies, and adapted work practices to the lessons learnt. Our reflections show how valuing the experience of those working in schools is essential to flip less than ideal system realities such as out of field teaching into valuable opportunities to develop expertise. (Selvakumaran, in prep)

In this paper we explore the learning possibilities of out-of-field teaching and the role that the school context plays in making the inevitable disruption caused by having to teach out-of-field an opportunity, instead of a destructive experience. In order to examine the learning possibilities, the boundary crossings lens as synthesised by Akkerman and Bakker (2011) is employed to: provide a focus on discontinuities that arise, such as disruptions in actions and interactions associated with their knowledge, confidence or practices as a result of changing roles or contexts; and the learning and shifts in professional identity that accompany successful boundary crossings. The boundary crossing lens enables analysis of teacher learning by focusing on how teachers identify differences between their practices, seek out supports, and reflect on the changes that are involved for them as they learn new content and develop new practices.

**METHODOLOGY**

The project is longitudinal and uses case study methodology (Stake, 2005). Teachers from six schools who were either science and/or mathematics teachers teaching another subject out-of-field, or out-of-field teaching mathematics or science, were interviewed over two or three years. Mentors to these teachers, the school principals, and other leading teachers from each school (where possible) were also interviewed.

Individual teacher interviews focused on their experiences of teaching out-of-field and in-field, their background, their learning, and influences of the contextual factors. Year 2 and 3 interviews focused on changes in their teaching load and attitudes and beliefs, and depictions of what it felt like to be out-of-field.

Interviews involving the out-of-field teacher and their mentors (or critical friends) focused on the mentoring relationships in year 1 and then changes in teacher capabilities and enjoyment in year 2 and 3 interviews.

Reflective interviews with teachers following private viewing of video-recorded in-field and out-of-field lessons focused on how the teaching reflected teachers’ learning in year 1 and 2 interviews and their beliefs in year 3.

Interviews with principals and leading teachers focused on school context, policies and practices, and perspectives and attitudes towards out-of-field teaching in year 1. A follow-up interview in year 3 provided an update on these contextual factors.

A categorical analysis of all interview data resulted in a set of codes that were emergent from the data. All interviews were independently double coded by two researchers. For this presentation, a preliminary analysis of data focusing on three schools is used to highlight the effects of school context on teacher learning. Therefore, categories of data relating to the codes of ‘School context’, ‘teacher learning’, ‘supports’, cross referenced in relation to the three schools, have been used to develop case studies and vignettes about how the schools created cultures of support, innovation and collaboration. These schools were selected
because they represent positive cultures that supported teacher learning, and have teachers teaching across various STEM subjects, including Science, Technology and Mathematics.

RESULTS

Case studies of the three schools will be provided to illustrate how the school context influences teacher learning, including the supports enabling teachers to develop confidence and build capacity. These scaffolds were seen to be strongly linked to whether there was a culture of support, innovation and collaboration within the whole school or amongst teacher teams; these three elements are described here. The presentation will provide a cross-case analysis of the various supports used across the different schools.

Also vignettes of some STEM teachers will demonstrate how the school context and broader support networks and engagement with professional learning influenced their pathways of learning to teach a new subject. One teacher at School VICE has been included here, but the presentation will provide a vignette for teachers from the other schools.

School VICE (time in project: two years)

Culture of innovation: The principal encourages teachers to explore their passions and develop exciting curriculum based on their interests. This may involve teachers teaching out-of-field, for example, a technology teacher teaching air and flight, a physics teacher teaching textiles. During the project the school was working out how to incorporate STEM.

Culture of support: Generally teachers were positive about the support structures within the school. All teachers are in the one staff room where they can gain support from neighbouring colleagues. An official Maths mentor is available for all mathematics staff, but he provides particular mentoring for a beginning Maths specialist teacher and an out-of-field applied mathematics teacher. The principal and vice principal have chosen to continue to teach (in most Australian schools principals are purely administration), enabling the availability of more funds for teacher professional development and schools resources than if the funds were used for teaching relief staff.

Culture of collaboration: Teachers were encouraged to work together outside of class to provide support, and within discipline groups to work together to meet common discipline-oriented goals, and as cross-discipline teaching teams to create new units. This is illustrated in Eliza’s vignette.

Eliza

Eliza was a General Science, Physics and Information Technology teacher who was asked to teach Year 8 Textiles. Eliza was interviewed individually (four times) and with her mentor or critical friend (twice) during her second and third year of teaching. Textiles was technically out-of-field except that she designed and sewed her own clothes, so had the technical skills needed to teach the subject.

In her first year of teaching Textiles, Eliza had contact with the previous teacher so could get some support from her. She did not seek formal professional development. In her first year of teaching Textiles (her second year of teaching), she encountered difficulties in knowing how complicated to make the design challenges and underestimated the degree of support that students would need. In inviting her to take on the textiles teacher role, Eliza’s principal encouraged her to use conductive thread as a way to bring science into the design process.

Initially she saw this as something for the future, but by her second year teaching it she had redesigned the learning tasks to include conductive thread, LEDs, and button batteries as
part of the design and construction. She was also working with the art teacher to ‘start up a subject that is going to incorporate… modern or digital and analogue techniques’.

**School VICC (time in project: three years)**

*Culture of innovation:* the school supports a culture of innovation in terms of how it structures its year 7-9 program as an integrated learning program of English, Maths, Humanities and Science, and in terms of its uptake of digital technologies for students and teachers (with a flow-on effect to parents). Innovative practices are encouraged so if a teacher wants to try something new, it is discussed and opportunities provided as long as it is possible within existing structures.

*Culture of support:* There exists an official mentor program for first year teachers but also teachers commented on support from leadership. There is a belief that they are supported and can ask for further support if needed.

*Culture of collaboration:* The physical structure of the school enhances opportunities for collaboration across a year pod. It also reduces the need for ongoing mentoring. Collaboration is seen as important, but there is a recognition that it is not working as well for teachers in classes higher up the school – outside of the integrated learning program – where opportunities for collaboration exist within discipline areas, but not more widely.

**School NSWA (time in project: three years)**

*Culture of innovation:* This was evident mainly as teachers improving their own teaching within their subjects, for example, the out-of-field Maths teacher was innovative in bringing strategies from PDHPE to enhance his Maths lessons, and in the school introducing some project based learning initiatives (some of which were STEM related). While there was some hope to timetable Science, Mathematics and Technology together to facilitate integrated STEM, it was prevented due to constraints with the timetable.

*Culture of support:* Support is provided predominantly through the proactive and committed efforts of an instructional designer who subsequently became principal. Her support is particularly sensitive to the emotional needs of the out-of-field and only secondary Mathematics teacher, and explicitly focusses on his developing identity as a Mathematics teacher.

**CONCLUSION**

In these schools, the culture of support was largely initiated and fostered by the active involvement of the principals in facilitating strategies and/or providing formal structures for support (eg. mentors or others allocated to support teacher learning). Learning is enabled when there is appreciation of the difficulties that teachers face and the impact on identity development (School NSWA), and a belief that they are supported (School VICC). A sense of permission to seek and ask for support (eg. professional development) is evident across the three schools, which gives teachers some autonomy to engage in learning at their discretion. The teaching-principal at School VICE shows the school’s commitment to ensuring the resources are available for teacher learning.

The culture of innovation was demonstrated particularly at the two VIC schools. At School VICC totally rethinking curriculum enabled multi-disciplinary teaching teams to make meaningful links between subjects. This meant that teachers needed to consider the content and teaching approaches from other subject areas, but they learned these through working closely with each other. School VICE was using STEM as a vehicle for change where teachers could follow and apply their passions within subjects (within textiles) and
across subjects (across technology and art). A culture of innovation creates a breeding ground for learning, and for out-of-field teachers, this can allow them to be part of the process, especially if they are equal contributors to the change, or their expertise is valued and needed to ensure the team functions adequately. In both of these situations there is a spirit of sharing, learning and distributed leadership.

Collaboration around the STEM subjects is linked to innovation – where collaboration is enabled through the school infrastructure (eg. close proximity of staff in a small or single staffroom) and to create new units or activities, there is potential for teachers to learn from each other as well as reflect more deeply on their own subject areas. The examples provided will show how STEM can be used to develop new ways of working together in order to maintain quality teaching through effective teacher learning processes.

REFERENCES


ABSTRACT

In open-ended project-based learning courses, large class sizes make equitable grading a challenge. The subjectivity and diversity of Problem-Based-Learning (PBL) outputs introduces inequity when multiple graders work in parallel. On the other hand, the burden of maintaining a consistent grading precedent over a large number of sequential project demonstrations is overwhelming for a sole grader and leads to similar inequity. A software tool is developed to remedy this. It displays a sorted list of photos and grades to ensure that subsequent projects grades conform to the precedent. Photos are organised by lab section and may be sorted by grade, team name or chronology. The tool is developed to improve grading equity in a 3rd year Electrical Engineering Design Studio course with an enrolment of 136 students divided into 34 teams. Initial results demonstrate significant reductions in the deliberation time that is required to arrive at a grade, particularly later in the demonstration process when equitable grading is most challenging. It is also found to improve the confidence level that assigned grades are appropriate relative to one another. The software tool is implemented in Python (open-source).

Keywords: Grade equity, Large class, Project based learning

INTRODUCTION

University enrolment in North America has grown steadily over the past 10 year. In Figure 1, undergraduate enrolment in the department of Applied Science at the University of British Columbia (UBC) is shown to have increased by 65% in 10 years, from 2007 to 2017 (UBC, University of British Columbia Department of Applied Science, 2017).

![UBC Engineering Undergraduate Enrolment](image)

Figure 1. Undergraduate enrolment in APSC at UBC
Mathematically, enrolment need not impact class size as long as faculty recruitment keeps pace. This is not the case with Problem-Based-Learning (PBL) due to resource demands that can make multiple parallel sections impractical, regardless of staffing. Lab spaces, technical support staff, prototyping equipment and qualified TAs are all expensive and limited resources which may prohibit parallel sections due to scheduling and time conflicts. In engineering programs, PBL courses are fast becoming the (Helle, Tynjala, & Olkinuora, 2006; Macias-Guarasa, Montero, San-Segundo, Araujo, & Nieto-Taladriz, 2006; Mills & Treagust, 2003), so class sizes at many institutions can be expected to grow alongside enrolment trends.

In lecture-based courses, grading workload is easily subdivided and equity is relatively independent of class size. A study evaluating assessment strategies (Duncan & Noonan, 2007) reports little correlation between class size and assessment practices. While this may be true for conventional examination grading, PBL grading is much more susceptible. An open-ended design project has no “right answer”. It is uncertain what students will deliver so it is unclear how to prepare a grading rubric. The following features distinguish PBL grading from exam grading.

- Grading is subjective
- Graders must be qualified in all aspects of the entire project
- Student teams are diverse in their approach
- Student teams routinely deliver more than what is asked

Maximising grade equity under these conditions imposes the following constraints.

- A common grader or grading team must assess all projects
- The grading team must be qualified in all aspects of the project
- The grading criteria must be adjusted in real-time to accommodate unanticipated outputs
- A mental inventory must be kept of all prior outputs, throughout the grading process

An inter-disciplinary capstone design project has such diverse technical content, the only person qualified to evaluate it in its entirety is usually the course professor. And since adjusting the grading criteria should also be handled by the course professor, a sole grading team is unavoidable. But assessing many projects sequentially over a span of several days while keeping an accurate mental inventory is very difficult, if not impossible, and the author is no exception. This leads to a lack of confidence in grading equity that is the primary motivation for this work.

A required course in the 3rd year Electrical Engineering program at UBC is ELEC 391 - Design Studio. This is a 13 week PBL course where students are assigned a capstone-style project which incorporates their entire 3rd year experience, or as close to it as possible. Topics include:

- Energy Systems
- System & Control
- Electro-Magnetics
- Circuits & Devices
- Real-Time Systems
The broad scope, high enrolment, and tight time constraints of this course present many challenges that have motivated a stream of pedagogical innovations that include formative assessments and time optimisation (Stocco, Rosales, Galiano, Liu, & Feixo, 2016) and partial integration with a pre- requisite course (Stocco, Galiano, Paz, Rosales, & Feixo, 2017).

In the Spring 2018 term, students were asked to develop an electro-mechanical 2-DOF real-time control system that combines a laser with a robotic spherical wrist to draw a figure on a surface (see Figure 2). Students designed and constructed mechanically commutating motors, optical encoders, digital and power circuits, and a PID controller running on a microcontroller to command the system. All system components were modeled and simulated in Matlab/Simulink so that formal design techniques could be used to develop and optimise the PID controller.

Figure 2. Schematic of ELEC 391 Design Project

A class of 136 students were divided into 34 teams of 4 students. Evaluations allowed 15 minutes for each demonstration and 5 minutes for deliberation and grading. That equates to a total of approximately 12 hours which was split over two days so it could be done sequentially.

This was the 4th year that this course had been delivered. In each of the previous 3 years, there had been a noticeable and inevitable decay in the confidence level regarding the fairness of each subsequent grade, as the memory of past projects and grade allocations faded during the deliberation process. In this paper, a software tool is developed which provides a snapshot of all past projects and their associated grades. It improves grade equity and the confidence in grade equity to more fairly reward students for their efforts while expediting the deliberation process.

SOFTWARE TOOL – MARK-IT

A software tool is developed to help maintain an established precedent when a large number of diverse outputs are being compared. It accomplishes this by meeting the following requirements:

- Simultaneously display a photo of each project
- Display the team name associated with each photo
- Display the assigned grade for each team photo
- Organise the team photos chronologically by lab section
- Sort the entries in each lab section chronologically, by team name, or by grade
- Allow grades to be modified
- Archive and retrieve data
The tool is written in Python (Python, 2017) which is a free, open source, scripting language that allows rapid development of PC applications. To run the tool, Python 3.6.5 or later is installed on the host computer. The tool is contained within a single text file which may be viewed and edited using any text editor.

- Mark-It.py Python script

To use the tool:

1. Run the application (double-click the Python script)
2. <optional> Load a saved workspace
3. Load a new photo of a student project
4. Click on a photo to see an expanded view and/or change the grade
5. Repeat steps 3 & 4
6. Save workspace to an archive file

When the tool is run, a blank screen appears with three menu options and three sorting options. The associated sub-menus are displayed in Figure 3.

- Menu Options
  - Load
  - Save
  - View

- Sorting Options
  - Grade
  - Team
  - Chronological

![Figure 3. Mark-It Menu & Sub-Menu Options](image)

Each time a project is evaluated, a photo is taken and loaded onto the computer. The “Load / New Photo” menu option is used to load the photo into the workspace and assign it to a lab section. The “New Photo” screen is shown in Figure 4.

![Figure 4. New photo pop-up screen](image)
Once a photo is loaded, it appears in the workspace with the team name and assigned grade. Clicking on a photo opens a pop-up window that expands the photo and prompts for a grade change (see Figure 5). If no grade is entered, the existing grade is retained.

![Figure 3. Expanding a photo & changing a grade](image)

All photos in a section are displayed on the same row in the workspace and the columns may be re-organised by clicking on the any one of the three available sorting options. For example, clicking on “GRADE”, orders the photos in each lab section (each row) by grade (see Figure 6).

![Figure 4. Workspace sorted by Grade](image)

The workspace may be re-sized to fit a particular computer screen by clicking the “View / Resize” menu option which opens the pop-up window shown in Figure 7.

![Figure 5. Resize pop-up window](image)
The “Save” menu option provides two options for archiving the workspace. Clicking the “Save / Workspace” menu option saves the workspace configuration to a text file which can be re-loaded using the “Load / Saved Workspace” menu option to resume the current session. The text file is self-explanatory and may be edited using any text editor to correct errors such as misspelled team names or to change where the photos are stored. The text file is stored in comma delimited CSV format so Excel may be used to view or edit the file by changing the filename extension to “.csv”.

Clicking the “Save / Export Grades” menu option saves the team names and grades to a text file which may be imported into an Excel spreadsheet that is used to record student grades. Excerpts from the two archive files are shown in Figure 8.

![Figure 6. Archived workspace text files](image)

**RESULTS**

The tool was developed in Summer 2017 and was initially deployed in the Spring 2018 term. Projects were evaluated 3 separate times in 4 week intervals throughout the term. During each evaluation cycle, 34 projects were evaluated over two days with 6 projects per lab section, each spanning 2 consecutive hours, with a total of 20 minutes allocated to evaluating each project.

In prior years, each 2-hour session would go progressively over-time with each subsequent lab section. As the number of graded projects grew, 5 minutes became increasingly insufficient to identify how a particular project ranked, with respect to all others. The first 2-hour session would conclude 10 minutes late (typical), the next would conclude 20 minutes late (typical), and the final 2-hour session which would conclude close to an hour late (typical). After 12 hours of evaluations over 2 days, fatigue and confusion combined to make timely decisions impractical. Eventually, one become overwhelmed by the amount of information they struggled to remember, and the confidence level in grade equity degraded.

With the assistance of the Mark-It tool, each 2-hour block consistently concluded about 10 minutes late. This discrepancy is accounted for by unscheduled delays such as late starts, bathroom breaks, and informal feedback sessions. All evaluation sessions proceeded effectively on schedule with surprisingly little mental effort expended during the 5-minute deliberations. The level of difficulty did grow with the number of prior projects, but 5 minutes was always sufficient to arrive at a confident conclusion and record it.

With the assistance of the Mark-It tool, grading a project would proceed as follows.

- Estimate grade window – Fail / 50s / 60s / 70s / 80s / 90s
- Sort the projects by grade
- Identify subset of projects occupying the same grade window
- Compare current project to project subset
- Assign and adjust grades as necessary
For example, grading the 30th project might proceed as follows.

- **Estimate**
  - Requirements are met with no outstanding qualities
  - Assign to 80s (80% - 89%) grade window

- **Sort & Identify**
  - 4 projects already placed in 80s grade window
    - #1 – 88
    - #2 – 85
    - #3 – 84
    - #4 – 82

- **Compare**
  - Current project placed between projects #2 and #3

- **Assign & Adjust**
  - Current project assigned grade of 85
  - Project #2 grade adjusted to 86

In the above scenario, the 30th project is only compared to 4 prior projects that share its grade window. The other 25 are momentarily disregarded. Those 4 projects are organised chronologically by lab section and all 4 photos are expanded and displayed side-by-side. After a brief review of any notes that were taken, the specifics are recalled and grades are assigned and adjusted with relative ease. The grader is never faced with the formidable task of placing the current project with respect to all 29 prior projects.

**SUMMARY AND CONCLUSIONS**

Grading open-ended PBL course projects in a fair and equitable manners is a Catch-22 situation when enrolments are large. On one hand, the professor is the only one qualified to evaluate the multi-disciplinary projects, and must be involved to mitigate the individual biases and incomplete technical backgrounds of the teaching assistants. On the other hand, one person cannot reliably keep track of subtle differences between many projects that are demonstrated at a frantic pace over multiple days.

A software tool is developed to assist with this dilemma. It combines a photo of each project with the associated team name and its assigned grade. All photos are displayed simultaneously on the screen, organised by lab section. The photos in each lab section may be sorted chronologically, by name, or by grade. Photos may be expanded, grades may be changed, and the workspace may be archived to resume grading later, or to up-load the grades into an Excel spreadsheet. The tool provides a clear overview of all projects that have been demonstrated, and assists the grader to narrow down the relative ranking of each subsequent project by considering only the subset of projects that resemble the one being considered.

The initial deployment of the tool has virtually eliminated regularly observed time delays associated with deliberations occurring late in the grading cycle of a high-enrolment PBL course. More importantly, the confidence level in grading equity was markedly improved, indicating a stronger correlation between student output and awarded grades.

Deploying the tool does impose some overhead since a photo must be taken of each project and loaded onto the computer prior to the deliberation step, but it is easily satisfied by a teaching assistant with minimal photography skills.
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SECONDARY SCHOOL STUDENTS' ENGAGEMENT IN STEM EDUCATION IN A GAMIFICATION ENVIRONMENT

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ABSTRACT
The purpose of this study was to examine how a gamification environment enhance students’ engagement in Secondary School STEM education. The research was carried out with 120 Secondary 3 students, who aged between 13 to 14 years old from a secondary school in school 2017-2018. Students participated STEM-Treasure Hunt in after school, the tasks consisted of Mathematics, Science and integration for both subjects in STEM-Treasure Hunt. Quantitative method was used to examine the engagement in the task of Mathematics, Science and integration for both subjects, as well as the engagement in STEM-related activity. After the activity, the students were invited to answer a questionnaire.

Keywords: Gamification, STEM education, Engagement

INTRODUCTION
The field of Science, Technology, Engineering and Mathematics (STEM) influence almost every part of our modern life in this century (Brophy, Klein, Portsmore, & Rogers, 2008). Besides, the field of STEM facilities the development of modern and industrialised city (Rateille, Larose, Guay, & Senécal, 2005). Therefore, it becomes more important to train and cultivate engineers and scientists in different countries in future (Miaoulis, 2008).

Nevertheless, a great number of students feel that STEM related subjects are too challenging or/and uninteresting before studying the eighth grade (President’s Council of Advisors on Science and Technology [PCAST], 2010). As a result, students are not interested in studying STEM-related subjects in their post secondary studies. Holdren et al. (2010) states that students who show their interests in STEM education in the eighth grade are likely to choose STEM subjects in their post secondary studies than those students who did not show their interests in STEM education. Therefore, it is crucial for education authorities in different countries to enhance the eighth-grade students’ interests in STEM education.

Background of STEM education in Hong Kong
In Hong Kong, the Education Bureau (EDB) first proposed STEM education in the policy address in 2015 and released a Report on Promotion of STEM Education Unleashing Potential in Innovation for further support in 2016. In fact, the STEM education has been introduced in the United States of America for the last two decades.

Hong Kong is a bit lagging behind other countries in launching STEM education. Most secondary schools are still groping with how to implement STEM education into their teaching and learning practice. The first crucial aspect is to enhance students’ engagement in STEM education. Even though EDB has been actively promoting the STEM education among secondary schools, there are two obstacles that hinder the promotion of STEM education in Hong Kong. First, the teaching time is limited for the existing curriculum. Second, students lack of motivation in STEM related subjects.
Limited Teaching Time

Reports reveal that one of the strategies is that teachers should enhance teaching across curriculum among different subjects. However, Atkinson and Mayo (2010) state that teachers often teach the four STEM subjects separately. They do not use a unitary method to integrate the STEM subjects into other subjects.

In Hong Kong the secondary-school curriculum of Science, Mathematics and Technology subjects are developed separately with the Key Learning Area (KLA). They do not provide any guidelines to integrate among the subjects. Due to the limitation of teaching time and tight daily teaching schedules, teachers merely focus on the existing curriculum on each subject rather than on developing school-base-across curriculum.

Lack of motivation

Another strategy is that teachers should enrich learning activities for students. Most Hong Kong teachers are exam-oriented. Teachers focus more on how to achieve high academic results rather than to let students do hands-on activities. Therefore, students have got fewer opportunities to try hands-on activities. Besides, TIMSS reports reveal that most Hong Kong students are merely exam-oriented. They try their best to pursue better academic results but engage and spare less time in Mathematics and Science subjects. Hands-on activities may serve one of the methods to enhance students’ learning engagement in the said mentioned subjects.

Increase of the learning time by Informal Learning Environment

The Informal Learning Environment is defined as the environments that students learn outside classroom or university (Sullenger, 2006). The spectrum of Informal Learning Environment activities includes short-intervention experience such as half day hands-on workshops, after-school activities and camps organised by schools or universities. The common features of these short-intervention experiences help the secondary school students increase their interests in STEM-related activities and use hands-on activities for students to experience the STEM field.

After-school activities were thus adopted in this study. After-school activities not only provide extra time to enhance students’ motivation in STEM topics, but also provide them with various types of assessments. Students are engaged in different learning styles (Krishnamurthi, Ottinger, & Topol, 2013). Besides, STEM is related to after-school activities to provide an opportunity for students to learn from the activities themselves because regular school tasks mainly put emphasis on preparing students for standardised assessment (Sahin, Ayar, & Adiguzel, 2014).

Enhance student motivation by Gamification Environment

Gamification has been employed in different fields such as business, health and sports. Lee, Luchini, Michael, Norris, and Soloway (2004) show that gamification can augment students’ engagement and participation in activities as well as the learning outcome at different academic levels and grades in their schools. Students are passionately in the content. As a result students’ learning productivity was increased and a positive attitude towards learning was enhanced (Kapp, 2012).

Therefore, it is extremely significant for education authorities in different countries to launch STEM education, especially in Hong Kong’s current situation. The informal learning environment activities embedded with Gamification and blended learning platform may be acted as an exemplar to promote STEM education and enrich students’ learning activities and motivation of learning.
LITERATURE REVIEW

Gamification

Gamification is defined as the use of game-base elements and game thinking in non-game context in order to motivate action, to engage people, to solve problems and to enhance learning (Deterding, Dixon, Khaled, & Nacke, 2011). The good practice of Gamification can engage students in learning activities because engagement has positive correlation with the successful learning outcomes for the students. It consists of persistence, satisfaction and academic achievement (Erdoğan & Sahin, 2010; Krause & Coates, 2008; Kuh, 2001; Programme for International Student Assessment [PISA], 2009).

Most studies expose that Gamification is emphasised in higher education and publicised in conferences (de Sousa Borges, Durelli, Reis, & Isotani, 2014).

The other related definitions for Gamification can be described by via two dimensions namely playing-gaming and parts-whole (Deterding et al., 2011). Serious games and Gamification are differentiated by the dimension of part-whole about gaming in the context. Toys and playful design have been differentiated by the dimension of part-whole about playing in the context (see Figure 1).

Game mechanics and game dynamics are the two essential elements for Gamification (Law, Kasirun, & Gan, 2011). Game mechanics are the rules that construct the game features to make the emotion of the players such as challenging, rewarding and fun that expect by game designer (Bunchball, 2010). Game dynamic is the interaction among the players by game mechanics (Zichermann & Cunningham, 2011). Besides, Dichev, Dicheva, Angelova, and Agre (2014) suggest that challenge, curiosity, fantasy and control are primary mechanisms for Gamification of learning to maximise efficiency learning.

Connecting Science and Mathematics

In early STEM education, teaching and learning emphasised science, technology, engineering, and mathematics subjects individually rather than on an integrative approach (Honey, Pearson, & Schweingruber, 2014). Therefore, students lost their interests in STEM learning in conventional ways. The most important concept of STEM education is integration. That is integration of STEM-related subjects in order to solve real-word multi-disciplinary problems (Breiner, Harkness, Johnson, & Koehler, 2012). Explaining patterns, describing and searching are three common processes of Mathematics and Science teaching and learning (Yore, 2011). In addition, scientific problem solving was assisted by
mathematics process skills (Charlesworth, 2015). Furthermore, So (2013) states that students using appropriate measurement such as calculation, tables and graphs in science inquiries in an extracurricular event. In this study, integration of Mathematics and Science tasks were thus adopted.

**Students Engagement**

Engagement is typically divided into 3 categories (Astin, 1984):

1. Affective Engagement – students’ feelings about STEM education (e.g. sense of belongings in activities or attachment of the teachers)
2. Behavioural Engagement – students’ behaviour towards STEM education (e.g. attendance, outcome or participation)
3. Cognitive Engagement – students’ beliefs in their own achievement on STEM education (e.g. students’ abilities to learn; teachers’ expectation for students)

In this study, the Affective Engagement concerning students’ engagement in STEM education was emphasised.

**METHODOLOGY**

**Research purpose**

The purpose of this study is to examine the students’ engagement in learning STEM subjects by using after-school activities in a Gamification Environment. Furthermore, we will also explore how practical experiences may benefit the implementation of STEM education in enhancing students’ engagement in learning.

**STEM-Treasure Hunt**

The STEM-Treasure Hunt was adapted and held at the end of the semester. This was a one-off activity and lasted around 2 hours. There were 6 check points and 8 to 10 questions in each check points, which composed of STEM subjects’ questions that were related to the curriculum in each STEM subject. The examples are shown in Table 1. The questions were to include the hands-on activities and the virtual task for students in each of STEM subject or across different STEM subjects. The questions were designed by five experience teachers, who have been teaching for over 10 years in secondary schools and their university majors are Biology, Chemistry, Physics, Mathematics and Computer Science. There were 120 Secondary student participants, aged from 13 to 15. Students were divided into groups of four. Each group had an IPad. After the students finished each task, they had to fill in their answers into the blended learning platform. The criteria of the champion are: First, the group that answered most of the questions. Second, the group that spent less time to finish all the check points.

**Table 1. Example of STEM-Treasure Hunt questions**

<table>
<thead>
<tr>
<th>Check Point</th>
<th>Subjects</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mathematics: Measuring</td>
<td>a. Using IPad to find an inclined angle and then calculate the height of building</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. Using estimated method to count the number of books in library</td>
</tr>
<tr>
<td>2</td>
<td>Mathematics: Logic</td>
<td>a. Using IPad to play online logic game</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. Playing Tangram</td>
</tr>
</tbody>
</table>
3  Science: Physics  
a. Based on circuit diagram to complete a circuit board  
b. Using the speed sensor to measure the speed of trolley and plot an acceleration-time graph  

4  Science: Chemistry  
a. Using PH papers test the PH value of the substances  
b. Using IPad to create an experiment for testing  

5  Science: Biology  
a. Using Human Anatomy Model, students have to put back the internal organ to the Model  

6  STEM  
a. Using the speed sensor to measure the speed of trolley and plot an acceleration-time graph  
b. Using drinking tube to create a 3D structure  

Here are examples for the stations  
1. Making a Paper Prismatic Periscope  
Subject and knowledge  
Mathematics – Nets, Physics – Total Internal Reflection  
Description: Students have to use one piece of blank paper, two triangular prisms to make a paper prismatic periscope. Students have to design the paper folding and then try to create their own periscopes.  

2. Comparing the total amount of sugar in different packs of foods  
Subject and knowledge  
Mathematics – Rate and Ratio, Biology – Food Labels  
Description: Students will get five different packs of foods from their daily life (see Figure 2). Students have to find out which pack of food contains the most sugar. In addition, they have to find out the net weight and the amount of sugar per 100g.  

![Figure 2. Food packs](image-url)  

3. Testing substance  
Subject and knowledge  
Mathematics – Area, Chemistry – PH value
Description: Students have to cut the pieces of PH paper to test as much as possible the substance to see its PH value. However, the size of each PH paper should be at least 1 cm square.

4. Problem Solving

Subject and Knowledge
Mathematics – Compass and true bearing, Logic and Problem-solving

Description: Fourthly, there are two assigned tasks in this station. First, each student has got a big protractor, a ruler and a piece of hint card. Basing on the compass and true bearing, they have to find out an OR code in the school library according to the school floor plan (Figure 3). They have to walk 10 m from N35°E to the first point, and then walk 15 m from N35°W to the second point. Finally, they have to walk 1m from 210° to the third point. Then, they will get the QR code there.

![Figure 3. Floor plan of school library](image)

Secondly, students can make use of that OR code to assess a website. It is a logic game called ‘Wolf, Sheep and the head of Cabbage’. The goal of students in this online game is to move the wolf, the sheep and the cabbage to the left-hand side of the river in the man’s boat. Students have to click the wolf, the sheep and the cabbage on the shore to add them to the man’s boat, and then click the boat to move it across the river. Further, click the wolf, the sheep and the cabbage from the boat to put them to the shore. Students are told to watch out because the wolf will eat the sheep when it is left alone, and the sheep will eat the cabbage when it is left alone.

![Figure 7. Wolf, sheep and cabbage (2018)](image)
Data analysis

A mixed research approach will be used to determine the students’ engagement. Questionnaire will be conducted to examine the students’ motivation after the activity. 30 students in one class will be asked to do the questionnaire. The questionnaire will be divided into 3 parts. The first part is for demographic information. The second part consists of different types of questions. The third is for open-end up questions. The questionnaire in this part consists of 17 items. A 4-point rating scale, ranging from 1 (strongly disagree) to 4 (strongly agree), will be used to assess students’ engagement in STEM education. Descriptive statistic will be used to analyse each item in the questionnaire. In order to get an in-depth understanding of students’ engagement in STEM related subjects, the third part consists of 4 open-end up questions to get more relevant and detailed information from students. The data analysis and conclusion will be discussed at the conference.

REFERENCES:


INTERDISCIPLINARY KNOWLEDGE INTEGRATION METHOD AND DIGITAL ENVIRONMENT CONSTITUTION IN STEM EDUCATION

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ABSTRACT

STEM education is not a simple superposition of science, technology, engineering and mathematics as separate and discrete subjects, but the interrelated and deep integration of the four subjects, so as to promote the cultivation of students’ innovative spirit and practical ability. Therefore, the knowledge integration from an interdisciplinary perspective and the establishment of a high-quality learning environment are the keys to STEM learning. This article will analyse the interdisciplinary integration methods in STEM education, and explore the structure of the digital learning environment in order to better support the development of STEM education.

INTRODUCTION

STEM education originated from science education in American. In 1990s, the National Science Foundation (NST) first used STEM to describe events, policies, projects or practical activities involving more than two STEM disciplines, and STEM became an accepted term in 2001 (Yu, 2015). In recent years, STEM education is one of the research focus in the field of global education technology. United States, China, United Kingdom, Australia and other countries have brought STEM into the important element to promote innovation and reform in education.

Based on the ERIC database, Zhan Qinglong and other researchers quantified the related literature about STEM education from 2005 to 2015. The statistical results showed that the research of STEM mainly included the aspects of STEM education related theory, the application of STEM education research methods, the reform of STEM education school and the continuity of STEM education curricula (Zhan, 2016). This paper uses Scopus to analyse the thesis of the topic including STEM Education, and finds that the present researches on STEM education are more practical from theoretical research and more focus on the research of teaching methods, implementation conditions, cases and practice verification.

The specific implementation of STEM includes the penetration of STEM concept as a breakthrough point in a single subject, and the curriculum design as a whole from four disciplines--science, technology, engineering and mathematics. It also includes the development of community activities based on the integration of science, technology, engineering and mathematics. No matter which way of the implement of STEM, we can not do without the training of innovation spirit and practical ability through the knowledge of subject and it is inseparable from the appropriate support of digital resources and tools.

Consequently, based on the characteristics of STEM education, this paper will propose a method of knowledge integration and design tasks for interdisciplinary integration, and then design the constitution of the digital learning environment.
ANALYSIS OF CHARACTERISTICS AND INFLUENCING FACTORS OF STEM EDUCATION

STEM education has new features such as interdisciplinary (putting emphasis upon integrated interdisciplinary contents rather than every isolated subjects, see Figure 1); fun (selecting fun problems or projects to appeal students); process experience (making students learn by doing and experiencing); contextual (learning in a real—life context to avoid rote learning); cooperative (allocating several students into one group to finish complex tasks by sharing respective knowledge and energies); designability (designing their products based on questions and requirements); artistic (paying attention to humanity and social sciences when engaging in STEM Education); empirical activities (verifying hypothesis, solving problems, and designing products based on empirical evidences); and technology—enhanced (employing various technologies to promote learning and improve students’ technological literacy) (Yu, 2015). This paper analyses how to promote the reflection of STEM education characteristics from the three aspects: teaching content, teaching situation and teaching activities.

Figure 1. Analysis of Characteristics and Influencing Factors of STEM

Selection of teaching content

STEM education needs to carry teaching content in order to cultivate students' innovative ability and practical ability based on subject knowledge. For promoting the learning of STEM, the design of teaching content must consider the interdisciplinary and the deep integration of knowledge.

- Interdiscipline: The current knowledge is systematically divided according to the disciplines, so STEM education at least spans the four barriers of science, technology, engineering, and mathematics.
- Knowledge Integration: Corresponding to interdiscipline, STEM education is not a point or a shallow reference to subjects. It is not a simple superposition of subjects, but the discipline system to promote the integration of knowledge. Multidisciplinary integration is not a simple addition of the content of several disciplines, but the cooperation and communication between subjects by solving a particular problem or exploring a task.

Teaching situation design

In the implementation process of STEM education, it is necessary to present teaching contents through appropriate teaching situations and it is significant to inspire students' interest and motivation in learning, further support students' learning activities.

- Fun: The interesting learning situation is conducive to the achievement of STEM education. In order to promote interesting learning, situation can be created through rich-media, or through diverse teaching methods. Some projects gamified
STEM education content and embedded learning based on exploration and goal-oriented learning. Johnson et al. (2013)

- Authenticity: STEM education aims to cultivate students' innovative spirit and practical ability. Therefore, the teaching situation is as realistic as possible, which can effectively extract the students' previous experience, narrow the distance between the students, and improve students' learning motivation.
- Technicality: STEM education emphasises that students need to have certain information literacy and skills. The creation of teaching situations needs to embody a certain degree of technicality. This technologies include the technologies in the creation of situational through VR (virtual reality), big data, etc. On the other hand, the completion of situational problems requires the application of student experience technology.

**Learning activity organisation**

STEM education emphasizes students' autonomous learning led by teachers. Therefore, students' self-learning and personal experience are important factors.

- Process Experience: STEM education emphasises students in the task situation, analysing and solving problems by themselves, and finally constructing knowledge structure. So the process of learning activities needs to take full account of students' ability to experience the learning process, participate in the learning process and accumulate thinking experience.
- Cooperation: Cooperation is one of the characteristics of the constructivist learning environment. STEM education is also based on the constructivist learning theory. Therefore, learners' collaboration should be taken into the organisation of activities. In addition, due to the fact that the content of STEM education is real and complex, collaborative learning is of great importance.
- Designability: STEM education and maker education have a certain degree of commonality, among which the design is similar to that in the maker education. Learners need to experience the experiential process of problem discovery. They experience analysis and resolution, and use their own wisdom to accomplish design results.
- Empirical Activities: STEM education originates from science education, while positivism is an important way of scientific research. Empirical activities are the programs that students need to discover, verify and solve problems based on evidence, and they should follow the strict rules of science and mathematics in the design of the work. Yu (2015)

**INTERDISCIPLINARY KNOWLEDGE FUSION METHOD DESIGN IN STEM EDUCATION**

STEM education often experience the students' learning process through tasks or questions. The design of problems or tasks should reflect the interdisciplinary knowledge fusion. Therefore, this section first analyses the form of interdisciplinary knowledge fusion and then proposes specific task design methods.

**Interdisciplinary expression of knowledge fusion**

STEM education is not a simple superposition of science, technology, engineering, and mathematics education. Instead, it is necessary to interrelate and deeply integrate the four disciplines so as to promote the students' innovative spirit and practical ability. Therefore, in the process of instructional design, it is necessary to first clarify how the knowledge of
different disciplines is merged, how to integrate the inherent logic. In general, interdisciplinary knowledge fusion is reflected in the following four aspects:

**Differences in the same content in different disciplines.**
Because the same knowledge is in different disciplines, different emphasis is placed on differences according to the teaching needs of different disciplines. For example, both biology and geography include “ecosystems”. However, in the biology curriculum, they pay more attention to the composition of ecosystems, the food chain (web), and the ability to regulate ecosystems. In the course of geography, they emphasise the long-term evolution of natural ecosystems and its steady states (Han, 2008). Therefore, although the same knowledge belongs to two disciplines, it is itself unified. In STEM education, students may need to analyse the problems and tasks both from the long-term evolution of the natural ecosystem and from the current composition of the ecosystem. Also, in STEM education, students may need to synthesise different disciplines to form a complete awareness of a particular knowledge.

**The different roles of the same content in different disciplines.**
Because the same knowledge is in different disciplines, according to the logic of subject knowledge system, different terminologies are interpreted and applied. For example, in mathematics and in arts, concepts such as points, lines, and faces are included. In mathematics, however, points, lines, and faces are used as basic elements of graphics and geometry to perform numerical calculations; however, in arts, points, lines, and faces are the basic elements of composition, graphical depiction and exhibition. In fact, they are the same knowledge, but different application values. In STEM education, students may need to both compose pictures from the perspective of art and solve the problem of composition from the perspective of mathematics. It is also in STEM education that students may need to look at the same issue from different perspectives and solve it comprehensively.

**Mutual support of related content.**
Different disciplines provide different knowledge on the same topic. Knowledge can support each other. You can use Ausubel's advanced organizers principle to understand the mutual support of related content. It is often the case that after a certain subject has been studied in a course, knowledge can be used to supple and help to understand the new knowledge when relevant knowledge appears in other courses. For example, the geography course is divided into three main ethnic groups: white people, yellow people, and black people according to characteristics of the human body. The "biodiversity" in the biology curriculum can further explain this phenomenon. In STEM education, the use of mutual support of relevant content can help students correct wrong perceptions. On the other hand, it helps students to form deep understanding and promote problem solving.

**Independent content support**
Knowledge is independent and not related to topics. However, knowledge can support each other through logic reasoning such as causation and association. For example, in the geography curriculum, when the altitude is 100 meters above sea level, the temperature drops by about 0.6 degrees Celsius. In biology courses, broad-leaved forests are distributed at low altitudes, while coniferous forests are often distributed at high altitudes, which indicate that temperature has an effect on plants (Hu, 2015). Therefore, elevation-> temperature -> vegetation constitutes a fusion of knowledge. In STEM education, clever use of the logic of the causality and association between independent content can help the student's thinking and enlightenment, help students analyse the connection between subject knowledge, and help students solve the problem by sudden understanding.
Task Design Based on Interdisciplinary Knowledge Fusion

The logical starting point of the design task

Teaching task is the presentation of teaching content. The task design should change from discipline logic to application logic, and the organisation of the teaching content is optimised by learning the task of the content. In the past, learning content generally used discipline logic as a starting point to reveal the logic of the whole discipline one by one. Theoretically, it can deal with various practical problems. However, the content is often vague and difficult to activate and apply during the application process.

With the application logic as a starting point, knowledge and practice ideas will be used in the teaching by inspiring students' motivation and interest through situations and problems. This helps to promote students’ to find tasks, conceive tasks, summarise tasks, analyse tasks, evaluate tasks, decide tasks, exchange or share tasks. These all reflect the learning tasks of accumulate experience.

The key elements of task design

In order to ensure the scientificity, effectiveness and suitability of the teaching content reorganisation and task design, teachers should focus on the following key elements: The task or problem that embodies teaching content needs to be designed so that it can permeate the whole learning process; The task design needs to reflect the characteristics of interdisciplinary and knowledge fusion; Tasks should adopt real situations as much as possible to make students empathise with others and stimulate learning motivation and interest; Tasks should be open and inclusive so that students can be personalised learning and construct knowledge structure during the task; Tasks should reflect the accumulation of thought experience, such as conception, discovery, induction, choice, and evaluation, and promote the occurrence of higher-order thinking quality.

DESIGN OF DIGITAL LEARNING ENVIRONMENT SUPPORTING STEM EDUCATION

STEM education is a way of education that shows technical characteristics and advantages. The implementation of STEM education is inseparable from the support of digital learning environment. This part will carry out the design of the digital learning environment on the basis of the analysis of the characteristics and influencing factors of STEM education, as well as the form of STEM interdisciplinary knowledge fusion and the design method of the task. In order to implement STEM education, this paper claims that there should be environment which combine school-based teaching material and learning terminal (Figure 2).

![Figure 2. Structure of learning environment](image-url)
School-based textbooks

There are STEM tasks and related scaffolds in the school-based textbooks, in which the task points to the learning process of the students, while different types of resources and tools are provided to support the students' learning. The school-based textbook is based on the stereoscopic teaching material, and it is the teaching materials which consist of digital resources, environment and services, such as augmented reality technology, virtual simulation technology, learning analysis technology, intelligent diagnosis technology and so on. Compared with the traditional paper textbooks, the stereoscopic textbooks can be scanned digitally, which can flexibly connect the learning resources of the curriculum, the autonomous learning environment and the teaching analysis service. (Figure 3)

Learning terminal

The learning terminal takes the stereoscopic teaching material as the core, providing digital learning resources and environment.

- Digital learning resources: Each scanning logo for school-based teaching materials corresponds to digital learning resources. The types of digital learning resources include pictures, videos, interactive virtual simulation tools, testing exercises and so on. The images and videos mainly restore, visualise and materialise the contents of the school-based textbooks. The interactive virtual simulation tool software simulates the STEM tasks in accordance with the situation, environment, and machinery. It supports the students' practice and completes the transformation of the application knowledge to the ability. The test exercises can allow students to recognise the subject through the test topic, their own mastery level and targetted consolidation. The design of digital learning resources will be consistent with the four types of interdisciplinary knowledge integration mentioned before, so as to support the students' learning activities to the greatest extent.

- Autonomous Learning Environment: In the autonomous learning environment, VR, AR and other technologies can provide students learning situation reproduction. Students master the relevant theoretical knowledge through experiential learning, and integrate them into practice. Based on the app, students scan school-based teaching materials, enter into personal learning environment to complete the learning of digital learning resources, task operation, knowledge and skills testing. On the other hand, autonomous learning environment will collect students' data and record students' complete learning situation synchronously.

- The interactive environment: From the two dimensions of supporting teachers' teaching and supporting students' learning, it will provide strong support for
STEM education activities. Teachers can monitor students, control tasks progress, share resources, and deliver individual learning outcomes. In the course of learning, students can hand in the results to teachers, and receive feedback and suggestions. At the same time, students can form a learning groups to discuss and explore the learning tasks together.

- Learning analysis services: Detailed record and data analysis are based on students' learning content, learning schedule, learning time, and the application of learning resources in the autonomous learning environment and interactive environment. They find individual characteristics and learning styles of students, and recommend more suitable learning programs for students. It provides the basis for teachers' individualised guidance, excavates the characteristics of the student group and the situation of knowledge and skills. It provides decision-making support for the optimisation and proper intervention of the teaching process.

SUMMARY

The core orientation of STEM education is to cultivate students' innovative spirit and practical ability. Therefore, in the course of STEM teaching, the barriers of science, technology, engineering and mathematics education will be opened around the teaching objectives, so as to achieve the deep integration of knowledge. This study first analyses the characteristics of STEM education from three aspects: the selection of teaching content, the design of teaching situation, and the organization organisation of learning activities. It then refines the differences of the same content in different disciplines, the different functions of the same content in different disciplines, the mutual support of the relevant content, and the related support of the independent content. Then from the logical starting point and key points of the task design we put forward the task design method, and finally put forward the support environment of STEM education, which includes virtuality and reality integration. The design and presentation of school-based textbooks, learner analysis and personalised service will be the focus and direction of future research.

REFERENCE


IMPACT OF SPACING INTERVALS OF CLASS PERIODS ON CONCEPTUAL UNDERSTANDING OF ELEMENTARY STUDENTS IN SCIENTIFIC INQUIRY ACTIVITIES: CONTINUOUS VERSUS DISCRETE

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ABSTRACT

Scientific inquiry activities have been an important part of elementary science education. Since there is only one science class in a day or a week, a whole activity, also called a project, always spans several days or even weeks sometimes. This study aims to explore the impact of different spacing intervals of class periods (four continuous periods versus (VS) four discrete periods, with one period in each week) within a project on students’ performance. Two classes of 5th grade students (n=68) participated in the Thermodynamics Challenge, a 4-class-period Web-based scientific inquiry project translated and revised from the WISE project repertory. Student dyads in one class completed the project in four continuous periods, with only the traditional 10-minute break in between periods, while students in the other class completed the same unit in four discrete periods, with one period each week. Students’ performance was measured according to Knowledge Integration rubrics proposed by Prof. Linn. The result suggests that students in both conditions improved their understanding of thermodynamics significantly from pre-test to post-test. The comparison of increased scores between two conditions shows that the spacing interval among classes has no significant influence on students’ performance, but it’s advisable to shorten the intervals between classes inside a project so that students’ interest can be better maintained and the coherence of the inquiry process can be better guaranteed.

Keywords: Scientific Inquiry learning, Spacing Interval, Conceptual Understanding, WISE, KI

INTRODUCTION

With the development of science and technology, enabling students to gain scientific inquiry experience and accumulate scientific inquiry skills has become a universal consensus among the international science education community. Science inquiry activities have become an important part in elementary science education (Ministry of Education of the People's Republic of China [MoE PRC], 2017).

However, in many science classrooms, advantages of inquiry are challenged by diverse constraints, one of which is the lack of class periods. Most elementary schools of China only arrange one science class a day or even a week. Unlike other subjects, science inquiry
contains a series of processes including generating hypothesis, carrying out experiments and evaluating evidence (Klahr, 2000).

As a scientific inquiry class, called a project, usually needs more than one class period, it always spans several days or weeks. Thus, due to the long interval between class periods, inquiry activities are discrete and may lead to incomplete understanding. However, students may suffer from fatigue when the intervals are too short.

This study used the Web-based Inquiry Science Environment (WISE), a scientific inquiry platform from Berkeley, to carry out inquiry instruction. Containing a number of well-designed science projects, WISE has proven to be effective in promoting students’ coherent understanding of scientific principles (Vitale, McBride, & Linn, 2016).

This study aims to explore the impact of different spacing interval of class periods (four continued periods VS four discrete periods, with one period in each week) within a project on students’ performance.

THEORETICAL FRAMEWORK

Science Inquiry Instruction

Inquiry learning is a pedagogy of science education which recommends that students engage in authentic science activities in order to form a complete understanding of science concepts and scientific reasoning skills (Jonassen, 2010). Next Generation Science Standards (NGSS) framework describes eight essential practices for science inquiry including asking questions and defining problems, developing and using models, planning and carrying out investigations, analysing and interpreting data, using mathematics and computation thinking, construction explanations and designing solutions, engaging in argument for evidence, obtaining, evaluating and communicating information (Quinn, Schweingruber, & Keller, 2011).

The new Elementary School Science Curriculum Standards of China introduced in 2017 suggests that teachers need to provide students with enough time to conduct inquiry so as to achieve the instructional goals (MoE PRC, 2017). Thus, a science inquiry class always contains several class periods.

Some schools arrange these periods in a whole day so that students can complete an inquiry in a day, while other schools distribute these periods into several days or weeks due to a lack of class hours. But when considering the time arrangement, a “coherent” system of science education should also be taken into account, according to which primary school students can only maintain their interest and attention for 20 to 30 minutes (Ma, 2006).

Web-based Inquiry Science Environment (WISE)

WISE is a digital learning environment that scaffolds science inquiry designed by Prof. Linn’s research group at UC Berkeley. It is built around the theories of constructivism and knowledge integration (KI). KI is a well-structured science inquiry pattern, which involves eliciting ideas, adding ideas, distinguishing ideas and organising ideas to promote coherent understanding (Linn & Eylon, 2011). Hence, students can observe, analyse, experiment, and reflect while navigating WISE projects, while teachers can use online tools provided by WISE to guide and evaluate the learning process.

Designed for academic research, WISE has been applied for nearly 20 years, and many related studies have been conducted based on WISE in recent years. Experimental researches focus on four main aspects: (1) using different strategies to scaffold students’ learning, for example, focusing on collaboration and peer review (Matuk, Gerard, & Linn, 2015),
reflection (Donnelly, Vitale, & Linn, 2015), and explanations generation (Ryoo & Linn, 2014); (2) focusing on assessment and evaluation, including the comparison of automated and artificial scores, and comparison of different automatic scoring methods (Gerard & Linn, 2016); (3) using advanced technology to support students’ learning (Vitale, Lai, & Linn, 2014); (4) using WISE to promote teachers’ professional development (Gerard, Varma, Corliss, & Linn, 2011).

**METHODOLOGY**

**Participants**

Two experienced science teachers from two elementary schools in different cities implemented the WISE unit *Thermodynamics Challenge* with their 5th grade students. Only students who completed both the pre-test and post-test were included in the study. There were 48 students (26 females, 22 males) in class A and 20 students (11 males, 9 females) in class B.

Students in class A completed the WISE unit in four continuous periods with only the traditional 10-minute break in between (continuous) while students in class B completed the same unit in four discrete periods with one period each week (discrete) due to a lack of class hours. Some students did not complete the unit for diverse reasons including illness and overlapping school competitions (10 in class A, 15 in class B).

**Materials**

*Curriculum materials*

*Thermodynamics Challenge* unit translated and revised from the WISE project repertory was used as the curriculum material in this study. The unit can be found at the following web address: http://wise.bnu.edu.cn/project/141/#/vle/node20. *Thermodynamics Challenge* aims to solve scientific problems related to daily life, ranging from choosing suitable materials to designing hot/cold drinking cups. To accomplish that, students need to design comparative experiments, conduct experiments based on computer simulation (Figure 1), collect data, analyse data, make decisions, and write project reports.

Through this series of inquiry processes, students could (1) understand the process of science inquiry; (2) understand how to design comparative experiments; (3) promote the ability of reading and interpreting graphs; (4) develop reading and writing ability.

![Computer simulation in Thermodynamics Challenge unit](image-url)

*Figure 1. Computer simulation in Thermodynamics Challenge unit*
Pre-test and post-test

The pre-test and post-test items are translated and revised from Linn’s group ([http://wise.berkeley.edu/project/20721#/vle/node5](http://wise.berkeley.edu/project/20721#/vle/node5)), designed to assess (1) students’ ability to read and interpret graphs; (2) students’ ability to design and conduct comparative experiments.

Every item includes a multiple choice item and an open response item. Students should first select the answer and then use science evidence to explain the choice they made before. There are five items included in the pre-test and post-test.

Table 1 shows the general content of these items in pre-test pre-tests and post-test post-tests.

<table>
<thead>
<tr>
<th>Item</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Multiple choice + open response</td>
<td>Graph Comprehension (GC)</td>
</tr>
<tr>
<td>2</td>
<td>Multiple choice + open response</td>
<td>Graph Comprehension (GC)</td>
</tr>
<tr>
<td>3</td>
<td>Multiple choice + open response</td>
<td>Experiment Design (ED)</td>
</tr>
<tr>
<td>4</td>
<td>Multiple choice + open response</td>
<td>Experiment Design (ED)</td>
</tr>
<tr>
<td>5</td>
<td>Multiple choice + open response</td>
<td>Graph Comprehension (GC)</td>
</tr>
</tbody>
</table>

Table 2 is an example of an item.

| Q1 | Based upon these curves, explain which of the cups would keep a drink warm for the longest amount of time? ( )
|    | A. Cup A  B. Cup B  C. Cup C |
| Q2 | Describe what information from the graph you used to make this decision.

Rubrics and coding

All open response items in pre-test and post-test were coded with a knowledge integration (KI) rubric to determine a score reflecting the coherency of the response. These scores can help the teacher prompt students to convert from non-standard or partially relevant ideas into more standardised and complex ideas, therefore generating a more complex and coherent understanding of scientific phenomena or domain concepts (Linn & Eylon, 2011).
Table 3 is an example of KI rubric for the item in Table 2. All open response items were scored on a 5-point scale. All multiple choose items were scored on a 1-point scale.

Table 3. An example of the rubrics

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No answer</td>
<td>…</td>
</tr>
<tr>
<td>1</td>
<td>Off task</td>
<td>I don’t know.</td>
</tr>
<tr>
<td>2</td>
<td>Irrelevant or Non-normative ideas</td>
<td>I think cup C will keep a drink warm for the longest amount of time. Because the curve of C has the largest radians, so C has the longest time.</td>
</tr>
<tr>
<td>3</td>
<td>Unelaborated links between ideas, or partial idea</td>
<td>I think cup A will keep a drink warm for the longest amount of time. Because the temperature of A is always high, so it will keep for the longest time.</td>
</tr>
<tr>
<td>4</td>
<td>One scientifically valid link between two ideas</td>
<td>I think cup A will keep a drink warm for the longest amount of time. The initial temperature of three cups is the same. After 100 minutes later, the temperature of cup A is about 60 °C, while B is about 20 °C and C is 10 °C. So A have the highest temperature after 100 minutes.</td>
</tr>
<tr>
<td>5</td>
<td>Two or more scientifically valid links between ideas</td>
<td>I think cup A will keep a drink warm for the longest amount of time because the temperature decline trend of A is the gentlest. The initial temperature of three cups is the same. After the same time, the temperature of A remains highest.</td>
</tr>
</tbody>
</table>

Procedure

The procedure of this study is as follows:

1. Research preparation and pre-test. Researchers conducted training for teachers who would later act as instructors before the project was implemented, helping them understand the learning objectives and the design of Thermodynamics Challenge WISE unit, and learn how to carry out a science inquiry class based on WISE. The project content used by the experimental group and the control group on the platform is exactly the same. Finally, the students received a 30-minute pre-test before the class.

2. WISE instruction. Both students in class A and class B completed the same Thermodynamics Challenge unit on WISE by dyads in 4 class periods. Students in class A completed the WISE unit in four continuous periods with only the traditional 10-minute break in between (continuous), while students in class B completed the same unit in four discrete periods with one period in each week (discrete). Teachers in both class provided individual guidance to the students alike. After all the students completed the project, some groups made a presentation of their research report.

3. Post-test. Students received a 30 minute post-test three days after they completed the WISE project.
RESULTS

Pre-test

Before participating in the inquiry activity, students took a pre-test to evaluate their basic knowledge about this unit. The means and standard deviations of the pre-test scores were 10.19 and 2.40 for the continuous condition, and 8.15 and 3.31 for the discrete condition (GC); 7.04 and 2.05 for the continuous condition, and 4.35 and 2.52 for the discrete condition (ED).

A t-test performed on the pre-test showed that there is significant difference between graph comprehension and experiment design, with \( t = 2.84 \) and \( p < .05 \) (GC) and \( t = 4.60 \) and \( p < .01 \) (ED); that is, students in the continuous condition achieved a higher score than students in the discrete condition during the pre-test.

Post-test

To explore students’ learning gains during this WISE unit, a paired-samples t-test showed that there is a significant difference between pre-test and post-test in both the continuous and discrete conditions in graph comprehension and experiment design (see Table 4).

Thus, students (in both condition) gained in their understanding of ideas related to graph comprehension and experiment design from pre-test to post-test after using the WISE Thermodynamics Challenge unit.

<table>
<thead>
<tr>
<th>condition</th>
<th>item</th>
<th>N</th>
<th>Pre-test(M/SD)</th>
<th>Post-test(M/SD)</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>continuous</td>
<td>Graph Comprehension</td>
<td>48</td>
<td>10.19 (2.40)</td>
<td>12.46 (2.53)</td>
<td>8.44</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>Experiment Design</td>
<td>48</td>
<td>7.04 (2.05)</td>
<td>8.48 (2.48)</td>
<td>4.54</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>sum</td>
<td>48</td>
<td>17.23 (3.90)</td>
<td>20.94 (4.68)</td>
<td>8.27</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>discrete</td>
<td>Graph Comprehension</td>
<td>20</td>
<td>8.15 (3.31)</td>
<td>11.00 (3.89)</td>
<td>3.27</td>
<td>.004</td>
</tr>
<tr>
<td></td>
<td>Experiment Design</td>
<td>20</td>
<td>4.35 (2.52)</td>
<td>6.05 (3.15)</td>
<td>3.45</td>
<td>.003</td>
</tr>
<tr>
<td></td>
<td>sum</td>
<td>20</td>
<td>12.50 (5.53)</td>
<td>17.05 (6.61)</td>
<td>3.74</td>
<td>.001</td>
</tr>
</tbody>
</table>

Compared by condition

To compare the impact of spacing intervals on students’ performance, a t-test was performed on the increased scores of pre-test and post-test of both conditions, as shown in Table 5. The scores of students in the continuous condition increased much more than in the discrete condition in graph comprehension and experiment design, but the difference was not significant.

<table>
<thead>
<tr>
<th>item</th>
<th>continuous</th>
<th>discrete</th>
<th>t</th>
<th>p</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graph Comprehension</td>
<td>48</td>
<td>2.27 (1.87)</td>
<td>20</td>
<td>2.85 (3.90)</td>
<td>0.635</td>
</tr>
<tr>
<td>Experiment Design</td>
<td>48</td>
<td>1.44 (2.19)</td>
<td>20</td>
<td>1.70 (2.20)</td>
<td>0.449</td>
</tr>
<tr>
<td>sum</td>
<td>48</td>
<td>3.71 (3.11)</td>
<td>20</td>
<td>4.55 (5.44)</td>
<td>0.649</td>
</tr>
</tbody>
</table>
CONCLUSIONS AND IMPLICATIONS

This study shows how spacing intervals of class periods influence students’ performance in scientific inquiry instruction on WISE.

During the Thermodynamics Challenge WISE unit, students in both condition (continuous & discrete) made significant gains from pre-test to post-test, which demonstrated that the WISE project is beneficial to elementary students’ learning. This conclusion is coherent with studies of Linn’s research (Vitale et al., 2016).

In traditional science inquiry class, students usually conduct their inquiry by following the steps given to them by teachers. Thus, students cannot experience the complexity of science or form a coherent understanding of science concepts. But in WISE projects, students are provided with lots of opportunities to explore their own ideas, especially with models that make micro and macro scientific concepts both visible and testable (Linn & Eylon, 2011).

In prior studies, WISE has proven useful for middle and high school students. This study tested the effectiveness of WISE in primary schools in China. The result shows that WISE can also be applied in primary schools.

In addition, the comparison of increased scores between the two conditions shows that the spacing intervals between class periods has no significant influence on students’ performance. This result shows that the learning effect of scientific inquiry instruction in multiple lessons is not affected by the schedule. But based on the researcher’s class observation, though students can easily revise projects that they had learnt before on WISE, it still took the teacher in the discrete condition a lot of time to organise group learning and review WISE use and the contents of the project, since elementary students often forgot parts of the project due to the long interval. Besides, more students were reported to fail in completing the whole inquiry process in the discrete condition.

In addition, according to interviews with some students, some felt that it was boring to learn the same project for several weeks. Thus, though spacing interval has no effect on students’ learning performance, it’s better to shorten the interval between classes inside a project so that students can better experience a complete inquiry process and build a coherent understanding, while maintaining proper interest.

REFERENCE


APPLYING VISUALISATION TECHNOLOGY TO STEM EDUCATIONAL ACTIVITIES: A CASE DESIGN FOR SCIENCE AND TECHNOLOGY MUSEUMS

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ABSTRACT

STEM education emphasises multidisciplinary fusions and aims at close integration of science and engineering practices, the interdisciplinary concepts and core concepts. This has a lot in common with the characteristics of educational activities in science and technology museums. Visualisation technology can turn some static presentations of scientific phenomena into dynamic form. Meanwhile, the visualisation embedded in inquiry activities has a wide impact on students’ understanding. In this paper, we focus on the application of visualisation technology in educational activities, and introduce a case study (“the Journey of the Ball”) of visualisation technology being applied in a STEM educational activity in Chinese Science and Technology Museum. To identify the feasibility and usefulness of the case, we conducted semi-structured interviews with 10 experienced science teachers. The results show that this activity is considered to be a deep practice of integrated STEM educational activity in science and technology museums, and the visualisation technology can not only help students understand the dynamic nature of science, but also have the potential to improve the teaching achievements in science.

Keywords: Visualisation Technology, Science and Technology Museum, STEM Education, Educational Activities, Case Design

INTRODUCTION

In 2013, The Next Generation Science Standard released by the United States, first officially incorporated STEM education into the national education standards. The concept of STEM education is embodied not only in terms of knowledge of science, technology, engineering and mathematics, but also in the dimensions of social application of science, scientific technology and engineering, mathematical principles. The American scholars Robert Dyasi and Derek Bell referred to “practice”, “interdisciplinary concept” and “disciplinary core concept” as the three dimensions of STEM education. This shows that the combination of knowledge and practice would provide students with the possibilities to understand the core concepts deeply and develop important skills.

Educational activities based on exhibits play a very important role for science and technology museums in achieving educational goals. Science and technology museums enable the visitors to gain direct experience during the process of visiting exhibits and participating in educational activities related to exhibits. The scientific education carried out in the informal educational environments adopts more diversified methods and plays an important role in raising public interest and understanding of science, technology, engineering, and mathematics.
The same as in STEM education, “practice”, “exploration” and “direct experience” are all indispensable in the educational activities based on exhibits in science and technology museums. Therefore, developing STEM education based on exhibits in science and technology museums not only accords with their basic characteristics, but also has a natural resource advantage (Zhu, 2017).

The emerging visualisation technology of simulation in recent years can turn some static presentations of scientific phenomena into all-round dynamic form, making many abstract and incomprehensible contents vivid and interesting, reducing the difficulty of students in abstract thinking. We define visualisation as an interactive, computer-animated scientific phenomenon that includes scientific models and simulations (Linn & Eylon, 2011). Currently, researchers have developed powerful visual environments to explain complex scientific phenomena, which includes the Molecular Workbench, WorldWatcher, NetLogo6.0.3, and Physics Education Technology (PHET).

At present, visualisation technology is generally embedded into the learning environments such as WISE (web-based inquiry science environment) for classroom teaching research. Only a few people use it as an auxiliary tool to develop STEM educational activities in science and technology museums. It has been proved that the dynamic visualisation is better than the static method when the evaluation requires students to integrate the viewpoints of two contexts (Pedone, Hummel, & Holyoak, 2001). It shows that visualisation is particularly effective when the targeted scientific subject is essentially a dynamic process (such as a chemical reaction or mitosis), meaning that visualisation can help students sort out ideas about complex situations. On the other hand, most exhibits in science and technology museums have the dynamic scientific characteristics. Therefore, visualisation technology has huge potential in STEM educational activities in science and technology museums, which would help promote students to integrate their knowledge and achieve technical goals in STEM education at the same time.

**CASE STUDY**

Founded in 2002 by Nobel Laureate Carl Wieman, the PHET Interactive Simulations project at the University of Colorado Boulder creates free interactive math and science simulations. The team has developed more than one hundred visual materials for different disciplines, which can be accessed from websites (http://phet.colorado.edu/). According to PHET’s design report, PHET materials enhance the effectiveness of hands-on experiments in class where students can explore causality, quantitative relations and qualitative links (Finkelstein, et al., 2005). Designers hope that these materials will enhance students’ understanding of science through their exploration experience in daily life (see Figure 1).

![Figure 1. PHET visual screenshots](image-url)
Visualisation Technology Applied in STEM Educational Activities in Science and Technology Museum

“The Journey of the Ball” in the Chinese Science and Technology Museum is an exhibit loved by visitors. It contains a number of typical mechanical devices, including sprocket lift, linkage mechanism and so on. The exhibit displays the mechanical devices to the audience in a dynamic, operable form. Through the operation of various links, the rolling ball circulates in the exhibit. This dynamic display not only makes the audience have a more intuitive understanding of the mechanical device, but also brings fun to the audience.

However, according to the results of some researches on visitors’ perception, only a few visitors can understand the principles of the rolling ball movement, and a great number of visitors did not read the exhibit labels carefully, so they did not achieve targeted educational effect. Therefore, we hope to make use of visualisation technology to develop the STEM educational activity based on this exhibit, combining the educational and entertaining nature of the exhibit, so that the visitors can experience fun of engineering design and have a clear understanding of its scientific principles at the same time.

This paper takes the project of “The Journey of the Ball” designed by Science and Technology Museum in Heilongjiang Province as an example, on the basis of which the visualisation technology is embedded to optimise the design of the project. This case takes the manoeuvrability of the exhibit as the starting point and uses the “black box” conjecture method (exploring the internal structure and mechanism of black box by observing the relation between the information of external input and the information of black box output) to trigger the brainstorming.

In the activity, we use “problem introduction” and “task-driven” teaching methods to stimulate students’ curiosity and desire to explore the mechanical devices and show them the beauty of machinery. Students when participating in this activity learn to use visual materials of PHET on iPads by interacting with a simple PHET material.

During this activity, visualisation technology was embedded twice: the first time for the purpose of promoting students’ understanding of the characteristics of energy conversion through visualisation technology after watching the rolling ball exhibit; the second time, in the extension of the activity, where the activity designer offers students visual materials on PHET related to the activities, and supports learners to interact with the visualisations in order to solve their problems. (This activity’s flow chart is shown in Table 1)

Table 1. Flow chart of “The Journey of the Ball”

<table>
<thead>
<tr>
<th>Implementatio n steps</th>
<th>Activities of each step</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhibit introduction</td>
<td>1. Situation construction; 2. Brainstorm discussion using “black box” conjecture method. 3. Show the structure of rolling ball exhibit and let visitors operates it freely; 4. Introduce the internal structural characteristics of rolling ball exhibit.</td>
<td>![Flow chart image]</td>
</tr>
</tbody>
</table>
### Expert Interviews

In order to explore the feasibility and usefulness of the above case design, teachers and students were interviewed using a semi-structured interview protocol. The participants were five teachers (2 females, 3 males) and fifteen students (10 females, 5 males) who voluntarily joined the interviews. These teachers and students were chosen from science education discipline of pre-service teacher education faculty at a university in China. Teachers’ teaching experience ranged from 5 to 20 years ($M = 12.4, SD = 5.0$); all of the students were in the second year of their two-year bachelor programmes of pre-school science education. The interviews were conducted individually in the face-to-face form and the interview processes were video-recorded. The interviews included the following four questions:

| “Rolling ball” game | 1. Match: each group member operates each organisation in turn, starts the rolling ball, and makes the rolling ball movement by division of labor and cooperation.  
2. Link it: connect the mechanical device diagram with the corresponding mechanical name, detecting whether students can recognise each mechanical structure quickly;  
3. Find it out: using visualisation technology to introduce the labor-saving lever and the conversion between kinetic energy and potential energy, understand the function of the device.  
4. Say it: describe the principle of the linkage between each mechanical device and share the experience of the competition. |
|---------------------|---------------------------------------------------------------------------------------------------------------|
| Activity extension ——— Skilful machinist | 1. Contact: find out the connection between rolling ball device and things in daily life;  
2. Presentation: provide relevant Lego models for reference and introduce the building methods;  
3. Practice: design and build the mechanical model, complete the study sheet;  
4. Experiment: through experiments, verify the feasibility, rationality of the structural design, find out problems  
5. Improvement: analyse the problems found in the experiment, modify the design and manufacture;  
6. Development: watch visual materials and design a miniature rolling ball model, use programming and motor to make it an electric device. |
1. Does the case design reflect such concepts as “practice”, “inquiry learning”, “interdisciplinary concept”, “direct experience”, and is it a complete STEM educational activity?
2. Is it difficult to implement this activity in the science and technology museum, and does it take full advantage of the resources in science and technology museum?
3. Can this activity arouse students’ interest and positive attitude towards the educational activities in science and technology museums? Does it reflect students’ autonomy and exploration?
4. Does visualisation technology play a significant role in this activity? Can it help in combing complex knowledge, promoting knowledge integration, and expanding students’ creative thinking?

Based on the qualitative analysis of the interviews, the following conclusions are drawn:

a. Participants generally consider this activity to possess the features of in-depth integration of STEM knowledge and skills. The design of this activity can guide students to experience the exhibit deeply and help them obtain the cognitions of scientific method, scientific spirit and thought. The core knowledge and its application in the activity are reflected in a shallow and deep way.

b. The case design makes full use of the resources in science and technology museum to help visitors gain “direct experience” by “practice” and “exploration”, creating an environment for self-study and a way of knowledge construction for the participants. In the process of design, experiment, presentations, analysis and thinking, students can experience the fun of engineering technology.

c. Visualisation technology helps students distinguish different concepts and acquire interdisciplinary knowledge. In the extension of activities, providing visual materials related to activities can help enlighten students’ thinking. Teachers should support learners to interact with visualisation technology to solve their problems.

CONCLUSIONS

Carrying out STEM educational activities in informal educational environment can bring on a wide range of opportunities for scientific learning for young people, and it can also help to combine resources in the science and technology museums with school education more effectively. How to rely on exhibits to better carry out STEM educational activities is an important challenge for science and technology museums in exploring new educational practice models.

Findings from the current study indicate that when the well-designed visualisation is embedded in the STEM inquiry activities and merged with the exhibits in science and technology museums, it can help students clarify the dynamic nature of science, and has the potential to improve the scientific teaching results.

Furthermore, related studies have shown that visualisation embedded in inquiry activities has a broad and universal impact on students’ understanding (Linn et al., 2006). The value of visualisation for scientific learning is a controversial topic in the literature, but we think that the real problem is how to use visualisation effectively and properly in order to improve teaching. Visualisation can be deceptive when displaying scientific phenomena, so it
is necessary for activity designers to arrange activities carefully and develop new visualisation strategies in order to realise the full potential of visualisation in STEM activities.

REFERENCES


ABSTRACT

Although integrative STEM learning is gaining prominence, few research studies have been conducted to explore the development of STEM education related pedagogical practices. Such practices are needed so that students experience the way in which problems in STEM contexts are solved in real-life situations. The aim of this research was to explore the benefits of implementing a stage-based learning program that focused on the engineering design process and the development of inquiry skills concurrently. The research was qualitative in nature and the data were created from interviews with the teachers, who observed the implementation of the learning program. The perceived benefits were in relation to: the impact on students’ participation and engagement, the effectiveness of the learning sequence implemented, and the opportunities for further learning.

Keywords: STEM, engineering design process, inquiry, POGIL

BACKGROUND

Science, Technology, Engineering and Mathematics (STEM) education as an entity has been advocated since the early 1990s yet little progress has been made in making it mainstream in school curricula for the compulsory years of schooling. To facilitate the uptake of STEM education, recent research has explored implementation of STEM activities in classrooms (e.g., English, 2016; Fitzallen & Watson, in press; Kelley & Knowles, 2016; Moore & Smith, 2014; Ward, Lyden, Fitzallen, & León de la Barra, 2015) but the focus was often on the utility of the activities for learning content and few studies have explored the pedagogical practices that facilitate learning from integrative STEM learning activities.

Integrative STEM Education

It has become apparent that integrative STEM education can manifest in different combinations of two or more of the four disciplines (Becker & Park, 2011; English, 2016; Fraser, Earle, & Fitzallen, 2019). From a teaching perspective, this is problematic due to the pedagogy employed in the classroom being determined by the discipline expertise of the teacher or instructor (Wang, Moore, Roehrig, & Park, 2011). As a result, the engineering aspects of STEM activities are less likely to be the foci of integrative STEM learning opportunities. To compensate for that deficiency, schools take advantage of STEM outreach activities delivered by professional organisations and universities. Whilst such programs play
a valuable role in broadening student experiences (Laursen, Liston, Thiry, & Graf, 2007), their one-off and transitory nature limits their effectiveness. Although often delivered by experts in the field, such programs do not offer the opportunity for students to develop the inquiry skills necessary to utilise fully new knowledge gained from such programs.

**STEM Pedagogy**

In general, integrative STEM learning programs relate to real-life contexts and feature the development of proto-types or models to simulate authentic problem-solving scenarios (e.g., Moore, Guzey, & Brown, 2014; Ward et al., 2015). They also involve students taking an inquiry approach that incorporates working in groups, which fosters discussion about the problems and potential solutions (Kelley & Knowles, 2016). Moore and Smith (2014) contend that STEM integration can occur from two perspectives – context integration or content integration.

When related to engineering activities, context integration involves using the engineering design process (Figure 1) as a pedagogical means of developing learning about technologies through integration and application of mathematics and/or science (Ward, Lyden, & Fitzallen, 2016). Content integration involves purposefully targeting engineering and disciplinary content as learning goals. Little guidance, however, is available on the most effective pedagogical approaches needed to facilitate content integration and the learning potential offered by both aspects of STEM integration.

![Figure 1. Engineering design process](image)

A key pedagogical approach appropriate for accommodating learning about the engineering design process in conjunction with science content is process-orientated guided inquiry learning ([POGIL] Moog & Spencer, 2008). This a student-centred, constructivist pedagogy where the students are guided through content with a focus on active engagement with the learning process (Eberlein et al., 2008). It focuses not only on knowledge acquisition but also process skill development, which are achieved through the introduction, development, transfer, and consolidation of ideas according to a stage-based learning cycle.

This begins with an initial exploration phase where the requisite subject knowledge is developed, followed by concept formation, where the facilitator through well-constructed questions, guides students to develop understanding of the concept. The final stage is application, which integrates naturally into context-based and team learning environments. This pedagogy was developed for and is primarily used in higher education settings. It has, however, been implemented successfully in secondary science education (Trout, Padwa, & Hanson, 2008).
THE STUDY

The research reported in this paper investigates the implementation of a five-week learning program designed to develop students’ knowledge of STEM concept, as well as the requisite problem-solving and inquiry skills needed to leverage new knowledge gained to new experiences and contexts. The aim of the research was to determine the benefits of implementing a stage-based learning program that began with instructor facilitated guided learning activities and culminated in student-directed inquiry tasks. The learning program was developed in accord with the POGIL strategy (Moog & Spencer, 2008) to facilitate the application of the engineering design process as means of delivering learning about the science concepts embedded within the learning activities. The extended learning program was delivered to upper primary students by instructors with expertise in engineering fields from a School of Engineering and ICT at a regional university.

RESEARCH APPROACH

This research is qualitative and exploratory in nature. It adopts a pragmatist paradigm (Creswell, 2014) and utilises qualitative data to investigate the implementation of a staged-based integrative STEM learning program. It examines actions and situations to develop an understanding of the meaning of ideas by drawing on qualitative research methods and techniques. An emphasis is placed on developing an understanding of what works by examining solutions to problems to derive knowledge about the problems (Patton, 2002).

The Learning Program

The learning program involved the students being exposed to a staged progression of learning from guided inquiry through to student-directed activities centred on team learning. All activities in the program featured a hands-on component and the learning experiences progressively built upon each other. These experiences first aimed to support the development of understanding of electricity and related scientific concepts as well as to familiarise students with the engineering design process (Figure 1). Having established this foundation, the learning experiences aimed to facilitate students in developing the skills and confidence needed to translate scientific knowledge and design skills to solving practical problems. A summary of the workshops is provided in Table 1.

<table>
<thead>
<tr>
<th>Workshop</th>
<th>Scientific Concept Addressed</th>
<th>Engineering Skills Addressed</th>
<th>Learning Approach</th>
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<tr>
<td>1</td>
<td>Electricity and Circuits</td>
<td>Underlying scientific knowledge and experimentation</td>
<td>Guided Inquiry Individual</td>
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<td>2</td>
<td>Electromagnetism</td>
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<td>3</td>
<td>Sound</td>
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<td>4</td>
<td>Water Pressure</td>
<td>Application of the engineering design process in a real-world context</td>
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</tr>
<tr>
<td>5</td>
<td>Wind Turbines</td>
<td>Application of the engineering design process in a real-world context</td>
<td>Self-directed Inquiry Teams</td>
</tr>
</tbody>
</table>
In the first workshop students were introduced to the concept of electricity and learned about electrical circuits. In pairs, students constructed simple circuits on solder-less electronic toy brick kits by following picture-based instruction sheets. Students were then asked to answer questions related to electricity and circuits, in general, and the circuits they had constructed. Although the majority of the session was guided by the facilitators, segments of the session provided opportunities for the students to work autonomously to investigate which materials behave as conductors and insulators.

In the second workshop, the focus was on the application of the students’ acquired knowledge of electricity and electrical circuits to the concept of electromagnetism and how it can be used to generate electricity. Students explored magnets and magnetic fields using iron filing field line viewers. Students were then given kits which included all the requisite pieces to create a hand-powered light, utilising a small generator. Students were given no instructions on which components were required but were guided through the process of experimenting with component combinations until they could turn on the light. They then utilised these skills to create an electromagnet. Finally, they developed a relationship between the number of turns in a magnetic coil around an iron nail and the number of paperclips that could be attracted, based on data collected from numerous trials.

In the third workshop there was a shift from a focus on only learning about scientific concepts to developing design skills. In this workshop the students were introduced to the science of sound. They learned how sound is created, and the movement of sound waves and vibrations. They then drew on their knowledge of electromagnetism from Workshop 2 to construct simple speakers out of low cost materials. To construct a speaker, the students were offered several different construction materials for the speaker’s cone. These included paper, plastic, aluminum foil, and tin cans. The activity culminated in a discussion where students were encouraged to evaluate the difference each material had on parameters like clarity and volume of the sound produced.

In the fourth workshop, the focus was on developing engineering skills and how to utilise new scientific knowledge in problem solving. The session began with the students being given some new scientific knowledge about water pressure. This was introduced in the form of a group activity, looking at bottles of water with holes down the side and how the amount of water above the whole affected the pressure of the water exiting the hole.

The engineering design process (Figure 1) was then introduced formally. The students used the process in designing and implementing a water tower and distribution system capable of transporting water over the distance of a metre. Students were asked to start at the design stage and sketch out the basic details of their planned solution, including details such as the height of the initial reservoir above the ground, what size and shape the reservoir might be and how the water flow would be controlled on its’ way to the end point. The test and redesign aspects of the process were emphasised to encourage the students to exercise evaluative skills when testing their design to find features that needed improvement. The final designs were tested as a group, again with the focus on developing effective strategies for identifying potential improvements for each design.

The capstone activity was a design challenge, which involved designing and building a prototype wind turbine from low cost materials and a 2.5 Volt direct current (DC) motor. The performance of the wind turbines was measured by the output power achieved when placed in front of a strong fan. This activity required the students to exercise both the scientific knowledge and design skills they had developed and practiced in previous sessions to design, build and test their wind turbines without specific instructions.
Participants and Implementation

The learning program was delivered in four state-funded Australian primary schools identified as either regional or as having students from low-socioeconomic backgrounds. It was run with a total of 86 students from Years 5 and 6, encompassing ages 10-13 years. The program involved the delivery of five workshops over a period of five school weeks, with a two-week school term break after the third workshop. The first four workshops each ran for 1.5 hours. For the final workshop, the students involved in the program from the four primary schools visited their local high-school where they had a full day of activities, including the final workshop in the program.

The learning program was facilitated by undergraduate and postgraduate engineering students, who were STEM ambassadors from a university-based STEM Education and Outreach Team. Each school was allocated one senior facilitator who attended all the sessions with that school. Supporting the senior facilitator in delivering each session was one or two junior team members, who may or may not have attended all the sessions at the school. Changing the STEM ambassadors across the course of the learning program allowed the students to be exposed to expertise from different fields of engineering.

Data Collection and Analysis

The data for this study were created from post-program interviews with the three classroom teachers involved in the project. Although the STEM Education and Outreach Team delivered the learning program, the regular classroom teachers were in attendance. Their role was to not only support the implementation of the activities but to also observe the students so that they could comment on the benefits of the learning program.

A 45-minute semi-structured interview (Fontana & Frey, 2003) was used for collecting data from the class-room teachers. The semi-structured format allowed for the interviewer to elicit pertinent information about the unique experiences of the students. The interviews were transcribed verbatim and analysed using cluster analysis to determine the main themes that arose from the data (Creswell, 2014). Ethical approval for the project was granted by the Tasmania Social Sciences Human Research Ethics Committee. Pseudonyms are used to report the comments made by the teachers.

RESULTS

The key themes that arose from the teacher interview data were: the impact on students’ participation and engagement, the effectiveness of the learning sequence implemented, and the opportunities for further learning.

Participation and Engagement

All three teachers commented that the students were highly focused during the sessions and stayed on task. They reported that behavior, interest and engagement were either as good as in the regular classroom setting, or better. Gerard reported that before the sessions began he had concerns that the students’ behaviour may have been an issue because they were going to be doing activities that were outside of their usual routine. He was pleased to report that his concerns were unwarranted and attributed the high level of student engagement to the organisation and sequencing of the learning experiences. He said, “when it's something different and something out of routine, then it [behaviour] is an issue... so the fact that this was out of their routine and there were no behavior issues, just goes to show how well it was delivered....” Similarly, Felicity was impressed by the way in which her students maintained engagement with the various tasks. Christine, however, reported no change in student engagement, which was usually good.
The teachers mentioned consistently the students’ high levels of excitement during the workshops. They suggested that the high level of excitement was more than just interest in the “fun resources”. Christine said “... it was excitement about learning not just about gimmicky things”. When asked what level of excitement he saw in the students participating in the workshops, Gerard stated, “100%,” and added “... they were just up for whatever came their way”. Felicity also commented on high excitement throughout the workshops. She said, “They’ve been really excited, you know, they haven’t whinged about it or anything like that, which is really good”. The teachers all agreed that working through different activities that targeted the development of understanding of key ideas helped the students maintain interest.

The Learning Sequence
When asked to reflect on the learning program, Gerard remarked that the guided inquiry approach using the POGIL strategy supported his students to work independently. Christine was impressed with the way in which the learning sequence empowered her students to collaborate in groups. She attributed this to the way in which the students moved from working independently, in the beginning, to contributing to team goals by the end of the learning sequence. Felicity commented on improved collaboration and group work within the workshops compared to normal, “I think a lot of the way they worked in groups to create things [was] to share ideas and sort of take turns and exhibit the sort of things which sometimes they're not the best at”.

In relation to students who had not participated in the full program, Christine commented that it was obvious that those students had not been exposed to the engineering design process and had not developed their self-directed inquiry skills that the other students who had participated in the full program had displayed. She said, “I think they hadn't had that benefit of the previous sessions”.

Opportunities for Further Learning
All three teachers commented on ways in which they would use the engineering design process in learning activities. Christine observed that the students’ response to the design aspect of the activities was not as productive as she would have liked. She remarked that “some of [the students’] initial designs were very basic, sort of almost stick drawings”. She then went on to say that she saw the potential for her to provide learning opportunities for the students to develop their drawing skills later. Gerard also reported that his students were keen to extend the learning experiences beyond the designated lessons. Christine’s class opted to continue working on the wind turbines “because they wanted to try changing some variables”.

In follow-up sessions, Christine reported the students applied the engineering process to make decisions about modifications needed to optimise the wind turbines’ performance. She was impressed with the way in which they identified potential changes, revised plans, made modifications, and retested the devices. The motivation to extend their learning beyond the experiences offered was evident when the students conducted more research about wind turbines and presented their findings and the modified models constructed at a school assembly.

DISCUSSION AND CONCLUSION
The quest to explore how to teach STEM education and the type of learning activities that foster the STEM-based skills needed for solving problems in real-life contexts is ongoing (e.g., Fitzallen & Watson, in press). The research reported in this paper provides an example of a pedagogical approach that takes a stage-based strategy to learning that focuses on the
development of content knowledge and inquiry skills (Eberlein et al., 2008; Moog & Spencer, 2008) through the application of the engineering design process (Ward et al., 2016).

Traditionally, STEM inquiry-based learning involves working on projects that evolve over a period of time, such as design challenges involving robotics or solar panels (examples in Office of the Chief Scientist, 2016). Implementing and sustaining long term projects is not always feasible in the everyday classroom. Using different inter-related learning activities over the course of the learning sequence to support students to develop the skills to work together collaboratively proved to be beneficial, both in terms of developing the skills needed to be an “engineer” and the skills needed to collaborate within team-based work environments.

This research suggests such an approach engages students effectively in the learning process. Further research is needed to explore the impact of the POGIL on students’ content knowledge and ability to transfer that knowledge through the inquiry-based learning process in other contexts.

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YEAR 4 STUDENTS' EMERGENT REPRESENTATIONS OF SCIENCE AND MATHEMATICS CONCEPTS

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ABSTRACT

The project is an exploratory study of how 7 to 12-year-old Australian children represent scientific and mathematical concepts and processes, through creating drawings of dynamic phenomena encountered during simple physical experiments. This paper reports the results from three Year 4 students from the first round of data collection, in relation to the question: What science and mathematics concepts are demonstrated through children’s representations? Task-based interview techniques, using digital data-gathering devices were used to capture the drawing sequences, diagrammatic structures, verbalisations and gestures that children used to represent the changes, movements and relationships they observed. From these external representations, we infer the children’s cognition and assess their emerging representational skills. The limitations of the students’ emergent diagrammatic competence were highlighted by the additional thinking revealed through verbalisation and gesture. In general, the students’ drawings were descriptive in nature – showing what happened using, at most, two variables (such as height and speed). Explanatory or causal reasoning was expressed explicitly through spoken words, or unconsciously through gesture. The initial results have informed our ongoing research methods and suggest that future results may indeed be useful in proposing strategies for improving students’ representational competence and conceptual understanding.

Keywords: Representations, science, mathematics, primary students

INTRODUCTION

The increasing expectation for Australian primary schools to engage with integrated STEM education brings with it a range of pedagogical issues for teachers, who are not typically accustomed to deep interdisciplinary approaches for teaching and learning in STEM disciplines. Much more research is needed to “… make STEM connections more transparent and meaningful across disciplines” for both teachers and students (English, 2016, p3). One avenue for such research is to explore similar ways of ‘knowing and doing’ across disciplines. The research reported in this paper investigates synergies in scientific and mathematical thinking, from a child’s perspective, via their self-created representations of observed phenomena.

Representation is crucial disciplinary knowledge and practice in both science and mathematics. Accordingly, our research is framed by representational theory for learning mathematics (Goldin & Kaput, 1996) and meta-representational competence in science and mathematics (diSessa, 2004). Both theoretical perspectives emphasise the critical role that
self-created representations play in developing, and reasoning with, concepts. In both disciplines, representations such as models and diagrams, are not only summative physical displays, but also integral to emerging visualisation and reasoning processes. Therefore, our research focuses on students’ self-created representations, based on the view that representations are ‘thinking tools’ used for both internal (mental) and external (visible) conceptualisation and model building (Goldin & Kaput, 1996; Prain & Tytler, 2013). Despite the importance of representation in science and mathematics fields, the role of representational competency in children’s learning is surprisingly under-researched and under-emphasised in classroom practice (Bobis & Way, 2018; Prain & Tytler, 2013).

When considering the role of drawing as a form of representation it is important to make a distinction between pictorial drawings and mathematical/scientific diagrams. From an educational perspective, pictorial drawings can be seen as emerging depictions of understanding (diSessa, 2004), but have been negatively associated with problem-solving or progress in learning because they include extraneous information and omit critical elements (Diezmann & English, 2001; Preston, 2016). Diagrams differ from ‘pictorial’ drawings in that they depict only essential elements and spatial structures inherent in the information or phenomenon being represented. Concerns have been raised about the lack of attention given by teachers to explicitly supporting the development of students’ representational competence, and the missed opportunities to enhance the use of diagrams as productive thinking tools (Prain & Tytler, 2013; van Garderen, Scheuermann & Jackson, 2012).

Therefore, our research project is based on the proposition that young students’ representations, centred on their self-created drawings, can provide insights into their emerging understandings in science and mathematics. We are motivated by the likelihood that explicitly supporting the development of drawing in STEM learning experiences can assist students to focus on the key concepts and relationships that are needed to build knowledge and deepen conceptual understanding.

Three research questions focus this inquiry:

- How do children’s creation and development of representations embody evidence of cognition?
- What science and mathematics concepts are demonstrated through children’s representations?
- What developmental differences are evident in children’s drawings across the 7-12 years age-range?

The project is currently midway through data collection from 50 children (Years 2, 4 and 6) from six primary schools. This paper draws from the initial round of data collection from one school which served as a pilot study to refine our data collection methods and develop analysis frameworks. This report focuses on just one of the broader research questions: What science and mathematics concepts are demonstrated through children’s representations?

**METHODOLOGY**

The research uses Task-based Interview to collect qualitative data directly from children during their engagement with a simple physical ‘experiment’. The purpose of task-based interviews is to create opportunities for observing each subject’s responses to a problem or task and make inferences about his/her mathematical (or scientific) thinking (Maher, Sigley & Davis, 2014). In other words, the researcher uses the external
representations produced by the subject to infer internal cognition. The design of the ‘task’ is central to this methodology. The task must be sufficiently open-ended to allow for a range of responses, and in our study, be suitable for the age range of 7 to 12 years. It must also be representationally rich to facilitate inferential analysis (Goldin, 1993). Dialogue between the researcher and subject must also be carefully considered, so that questions, prompts and conversations do not prematurely interfere with the subject’s thinking.

In our study, each child participates in a simple ‘experiment’, such as dropping a toy parachute or sending a toy car down a ramp, then records their observations by drawing and verbalising. Examining a completed drawing alone allows only tentative inferences to be made about a student’s thinking. A verbal commentary by the student during drawing creation affords greater opportunity for reliable interpretations of the student’s reasoning. Drawings are therefore done with a digital pen (LiveScribe), that is equipped with a tiny camera and microphone, capturing the progressive formation of the representation and synchronising it with utterances. The data from the digital pen is saved in a form that allows the dynamic episode to be replayed. Talking naturally stimulates gestures, and gesture can reveal either unconscious processes, or communicate thoughts not readily expressed in words or by drawing (Garber & Goldin-Meadow, 2002). Video-recording is used to capture all dialogue and gestures, including discussion before and after completion of the drawing.

**Interview Protocol**

**Equipment:** A ‘ladder’ with 5 rungs, a ramp that can be hooked to any of the rungs, a free-rolling toy car.

**Procedure:** Task introduced as: “We are interested in finding out what children think about how toys work. Today we are going to see what happens when we start this car from different heights on this ramp”.

1. Ramp set on lowest rung - car held at top by researcher. Child asked to predict what will happen when the car is released. Then car is released.
2. Procedure repeated for the ramp placed on middle, then the top rung.
3. Child invited to draw and talk about what they saw and why they think it happened.
4. Researcher asks questions to clarify, elicit more information or encourage further thinking. For example:
   - Why have you drawn the ……?
   - Can you tell me more about……?
   - What was different? What was the same?
   - Why do you think this happened?
   - You said ….. happened. How have you/can you show that in your drawing?

**Data Analysis**

The first-level analysis is focused on individual student responses. A draft analysis proforma was prepared then trialled by each of the three researchers by applying it the analysis of the recordings from the same interview. Interpretations were discussed and compared, then adjustments made to proforma. Analysis of each student’s data was then carried out by a single researcher, then reviewed by a second researcher, who added an interpretive summary. The proforma has four main components:

1. Drawing – as captured by the digital pen
   - Perspective and features
• Sequence of construction
• Type (procedural, descriptive, explanatory)
• Concepts and relationships
• Annotations

2. Verbal - as captured by the digital pen
• Terminology
• Clarification of drawing
• Additional information
• Type (procedural, descriptive, explanatory)
• Concepts and relationships

3. Video and audio – as captured by the video camera
• Student’s predictions
• Gestures
• Additional information

4. Significant sequences or conceptual shifts – from all data sources
• Extracts that record sequences of significant meaning-making (such as dialogue between the researcher and student and/or changes to the drawing)

RESULTS

The data for this paper are drawn from the three Year 4 (approx. 10 years old) students from the first project school. Each student’s drawing is presented with comments about the key features, and interpretations supported by verbal and gestural data.

Student 1

Student 1 chose to draw a front view – looking directly at the ramp with the ladder behind it (See Figure 1). He drew three separate drawings – one for each ramp position – but there is some mismatch between the appearance of the ramp height and the intention expressed in both written and spoken words. That is, the second drawing appears to show the lowest ramp but the annotation and verbalisation indicates it is meant to be the middle (2nd) position. Student 1 did not draw the car.

Figure 1. Student 1’s set of three drawings
Student 1 demonstrated awareness of a relationship between the height at which the car started and the speed it attained, and attempted an explanation after prompting by the researcher, saying, “…cos the low ones will go slow a little bit, and umm if you go on the middle one it will go a little bit fast but not as fast as the other one. Cos they’re in different cases and the thing makes it go higher so it goes faster”.

The use of a hand gesture to indicate changes in angle when talking about the different ramp heights, suggests Student 1 was thinking about the relationships between the height at the top the ramp, the angle of the ramp, and the speed of the car’s descent, although angle or slope could not be depicted in the front-view drawing, and the terms were not spoken or written. Student 1 also showed interest in the car’s trajectory, attending to whether it travelled straight down the ramp or veered to one side and drew lines down the ramp to depict the path of the car.

In summary, Student 1 attended to the height and angle of the ramp and the relationship to the speed the car. However, his front-view drawing did not afford representation of his reasoning and instead he mostly used words and gesture to explain his thinking.

**Student 2**

Student 2 drew one drawing from a front-right-corner perspective that showed the ramp set on the highest position (See Figure 2). The three different events were depicted by drawing three cars at the bottom of the ramp – one on the end of the ramp, one just off the end, and another a little further from the end and upside-down. The cars where labelled L, M and H to indicate the ramp positions of low, middle and high respectively. This depiction is consistent with the student’s focus on what happened to the car at the bottom of ramp, with some attention to whether or not the car went straight while travelling down.

![Figure 2. Student 2’s drawing](image)

When asked about the differences in the car’s performance for each event, Student 2 maintained his focus on the bottom of the ramp, saying, “… when you put it in the middle its even and there’s no bumps at the bottom”, and, “… the highest, it went down but then it crashed over”. He appeared to be thinking about the angle of the ramp and made a hand gesture indicating the slope of middle-position ramp, but his attention was on how the size of the ‘step’ (bump) changed at the end of the ramp on the floor.

In summary, Student 2’s representations were almost entirely descriptive, with his attention firmly fixed on what happened to the car at the bottom of the ramp.
Student 3

Student 3 created two drawings from a side view, though the rungs of the ladder where also shown as if from the front view (See Figure 3). The first drawing showed the ramp at the highest position, but the ramp ended at the edge of the page before reaching the ‘floor’. A detailed car was drawn near the top of the ramp, with 5 or 6 ‘whoosh’ lines drawn behind it to indicate high speed. The second drawing showed the ramp at the middle position, the ramp drawn with less slope, and the car with only three ‘whoosh’ lines.

![Figure 3. Student 3’s pair of drawings](image)

The verbalisation confirmed reasoning about the causal relationships between the angle of incline, the speed of the car, and the force of gravity. In reference to the ‘whoosh’ lines he said, “That’s the speed because of gravity”. He also explained, “Ramp was lower and it was going a bit slower”. When asked what caused the difference in speed he answered, “The ramp because it was tilted more”.

In summary, Student 3 used a side-view drawing to show difference in the angle of the ramp and its relationship to speed, which was depicted using the invented symbol of ‘whoosh lines’. His spoken words confirmed his explanatory drawing and added the concept of gravitational force, which was not explicitly represented in the drawing.

DISCUSSION AND CONCLUSION

The car-ramp ‘experiment’ did indeed provide a natural synergy between the mathematical and scientific concepts of angle, speed, trajectory and forces, and young students’ representations (diSessa, 2004). Somewhat surprisingly, none of the students attended to the distance travelled by the car across the floor after leaving the ramp. (Subsequently, we now use a slightly heavier car for stability, and use floor-markers to show where a car stops moving, as well as providing optional streamers and a tape measure).

Interestingly, each student chose to construct their drawing from a different perspective.

Student 1 drew a front-view and so was not able to depict his interest in the relationship between ramp-height and car-speed – which he had to express with words. However, the front-view did allow drawing of the car’s trajectory down the ramp. In contrast, Student 3 chose a side-view which allowed the creation of comparative drawings showing the height-speed relationship. The connection between the choice of perspective and the concepts
central to the student’s focus, seems worthy of attention in our subsequent data collection and analysis. (We continue to search for previous research studies on this aspect).

The analysis of this initial data reaffirmed the importance of capturing all the representational forms utilised by each student as they interpret and explain their observations – as advocated by Goldin (1993), and Garber and Goldin-Meadow (2002). The limitations of the students’ emergent diagrammatic competence were highlighted by the additional thinking revealed through verbalisation and gesture. In general, the students’ drawings were descriptive in nature – showing what happened using, at most, two variables (such as height and speed). Explanatory or causal reasoning was expressed explicitly through spoken words, or unconsciously through gesture.

The variety in the responses from the three students emphasise the need to collect many more cases to build a comprehensive description of the ways in which primary-age students utilise representations to process and express scientific and mathematical concepts. The initial results have informed our ongoing research methods and suggest that future results may indeed be useful in proposing strategies for improving students’ representational competence and conceptual understanding.

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DEVELOPING PRE-SERVICE TEACHERS’ UNDERSTANDINGS OF STEM THROUGH AN INDUSTRY EXPERIENCE

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ABSTRACT

A common pathway to becoming a teacher is for preservice teachers (PSTs) of STEM to go directly from school to university to teaching, with many experiencing casual employment in the retail and/or hospitality industries. As such, STEM preservice teachers may have limited exposure to STEM-related industries. This lack of experience can lead to naïve views around the nature of STEM industries and their potential applications to student learning. The result is that the potential offerings of these industries are not included in lesson planning and unit development even though they offer real-world applications for students of all ages. This paper examines an innovative program at the University of South Australia that gives STEM PSTs the opportunity of an industry experience as part of their Initial Teacher Education program. Using qualitative data from an initial trial of the program with 29 students, this paper reports on the experiences of the PSTs involved and reports on their changes in understanding and readiness to incorporate connections to industry into their curriculum planning. Greater awareness of the nature of STEM-related industries and the multitude of connections they offer to teaching emerged from PSTs industry experiences. Further development around their understanding of what STEM teaching and learning might look like in schools were some of the key findings discussed in this paper.

Keywords: STEM, School-Industry partnerships, Curriculum planning

INTRODUCTION

The Australian Industry Group (AI Group), Australia’s peak industry body, has repeatedly called for improved School-Industry links across primary and secondary schools to lift student participation in STEM-related subjects (Australian Industry Group [AI Group], 2017). In particular, the AI Group indicated that School-Industry links and STEM programs in general require the engagement of secondary teachers for success. However, they concluded that while teachers were keen to engage with industry and that industry welcomed such connections, most teachers were unfamiliar with how to engage with industry and had no training in developing these connections.

This was reinforced in a 2018 report from the Department of Education and Training [DET] (2018), which examined Industry and School links and made a series of recommendations to optimise industry and school partnerships. This report highlighted the need for industry to be involved in supporting teachers of STEM-related subjects.
Industry can provide a means for teachers and students to understand the latest developments in STEM careers and experience the kinds of problems professionals are working on. This enables students and teachers to link real world practice to lesson content. (DET 2018, pg. 58)

Within this same report, Australia’s Chief Scientist requested industry to connect with Universities in order to support STEM teacher professional learning.

They (Industry) can work with intermediaries such as universities and TAFEs to supply contemporary content or technology that can be incorporated into teacher professional learning (DET 2018, pg. 6)

Clearly, these reports highlight the need for schools and industry to connect with teacher support and professional learning being critical for these links to be successful. This paper proposes that a prime time to begin making these connections is when the preservice teachers (PSTs) are undertaking their Initial Teacher Education (ITE) program. Provision of opportunities to experience first-hand how STEM concepts, skills and processes to be taught in schools are being applied in today’s industries along with ways of engaging with industry at this early stage of their careers builds the incentive and capacity for these future teachers from the outset.

LITERATURE REVIEW

The theoretical framework that underpins the research in this article is a pedagogy of place or place-based learning (PBL) that draws on the works of Dewey (1954), Smith (2002) and Sobel (2005). A pedagogy of place embraces authentic learning experiences and begins with recognising that people exist in a cultural context and acting on that context can change the person, the situation and the relationship that one has with that context. Such beliefs were raised in 1954 when Dewey identified the significance of connecting learning opportunities with students’ local communities through nature studies to develop a sense of place. Dewey (1954) argued that truly authentic learning of place required students to engage in real-world activities, solving real-world problems.

When learning has this purpose, the outcomes can have a genuine impact and inherent value for all concerned. For the industry partners, place-based learning provides an opportunity to give back to the community and to improve the STEM skills of potential employees (DET, 2018). While MacGregor and White (2016) found that final year pre-service teachers working in partnership with a local industry provided an insight into how STEM operates in an authentic context while building professional confidence and understanding.

Smith (2002) also defines place-based education as real-world problem solving, where students are engaged through identifying school or community issues they wish to investigate or address. In doing so, they are scaffolded to become “creators of knowledge rather than the consumers of knowledge created by others” (Smith, 2002, p. 593). For example, an industry experience provided PSTs with the opportunity to utilise problem-based strategies and industry collaborations as the impetus for planning future inquiry and problem-based projects in STEM education (MacGregor & White, 2016).

Such a view is not dissimilar to Sobel (2005) who positions place-based learning around the notion of working in collaboration with local communities (industries) and environments as a base from which to teach across learning areas. He highlights the hands-on and authentic learning that connects people and place, engaging students as active,
contributing citizens. According to Sorbel (2005), PBL helps students develop stronger ties to their community; enhances their appreciation for the natural world; and, creates a heightened commitment to serving as active, contributing citizens. Furthermore, community vitality and environmental quality are improved through active engagement of local citizens, community organisations and environmental resources in the life of the school (2005, p.7). Such experiences aim to foster 21st century thinking through interactively connecting to authentic and meaningful experiences.

The benefits for school students’ involvement with school-industry partnerships have been examined in projects, such as the ‘Gateway to Industry Schools Program’ (Watters, Pillay, & Flynn, 2016). This program involved students engaging with industry, often as part of STEM subjects and the research indicated benefits for the students including authentic learning opportunities and enabling school to work transitions. Other research (Hands, 2010; Hill, 2004) reported these same benefits and in addition found higher engagement with school and the development of teamwork and communication skills.

In terms of curriculum specifically, the report by Watters et al. (2016) highlighted the importance of teachers being able to access appropriate curriculum support. The Australian Curriculum Assessment and Reporting Authority (ACARA) through the ‘STEM Connections project’ (Australian Curriculum Assessment and Reporting Authority [ACARA], 2016) explored ways in which teachers might help students to recognise the importance and transferability of knowledge, understanding and skills within science, technology, engineering and mathematic disciplines. They also supported teachers’ professional learning in this area through the use of video examples of schools connecting with Industry (https://www.australiancurriculum.edu.au/resources/steam/illustrations-of-practice/).

There have been a number of international and national projects that have involved Industry placements for STEM teachers, such as the Teacher Industrial Partners’ Scheme (TIPS) in England (King, 2015). These and other studies highlight the potential benefits for participants including industry awareness (Purdy & Gibson, 2008; Zaid & Champy-Remoussenard, 2015), development of communication, teamwork and organisation skills and being better able to inspire students and guide career choices (King, 2015). Similar projects with PSTs (Gibson, 2013) indicated these same benefits as well as improved planning skills and being able to connect the discipline areas of STEM (Gibson, 2013).

Therefore, problem-based learning in teacher education can be viewed as a process for informing the professional identity, work and pedagogical practices of preservice and early career teachers. Through the provision of meaningful and purposeful learning experiences, PSTs develop a greater capacity for interpreting and adopting similar approaches in their own planning and teaching. The research study discussed in this paper extends the international experiences into the Australian context and examines the benefits for PSTs engaged in an industry experience prior to their final placements.

RESEARCH DESIGN

Context of the project

The Teaching for Tomorrow project was a two-year project to evaluate the industry experiences of PSTs. One of the aims of the Teaching for Tomorrow project was to support PSTs in developing the knowledge, skills and confidence to become leaders in teaching STEM upon graduation. In making industry connections through the project there was an opportunity for PSTs to learn more about the industry, its core business, who it employs and its relationship to STEM in education.
As part of their coursework, these PSTs were involved in an industry experience as they worked collaboratively in cross-disciplinary teams of four or five final year Science, Design and Technology and Mathematics PST’s to develop units of work in STEM.

The industry experience varied depending on the company they were working with, but required the teams to work onsite with their partner industry on a regular basis for between 8-20 hours to develop an authentic understanding of STEM in the workplace. The PSTs observed the skills and capabilities required for employment within the industry and to develop hands on learning experiences in STEM related careers to better inform their own teaching practice.

The developed units of work were aligned to the Australian Curriculum (Technologies, Science and Mathematics) and included a connection to the industry in which they were engaged. The PSTs were expected to draw on their industry experience as the impetus for planning. The PSTs presented their final units at a Teaching for Tomorrow expo to other preservice teachers, industry partners, University academics, teachers and Principals.

Research focus
The trial set out to explore a number of facets of the industry experience using the following questions:

1. What changes are evident in the conceptions held by PSTs around STEM as a result of their industry experience?
2. What do PSTs perceive are the key learnings taken from the industry-based experience?
3. How do PSTs incorporate the industry experiences in their planning to teach? What evidence can they provide?
4. What are the challenges experienced by PSTs in negotiating the industry experience? Which were overcome? Which remained challenges throughout?

Research sample
In 2017, 29 PSTs participated in the trial from design and technology (N=13), science and/or mathematics (N=16). Seven companies participated in the industry experience across a range of areas including Defence, Food production, Advanced Manufacturing and Fashion.

Data collection and analyses
The PSTs responded to questions related to their understanding of STEM through a pre and post survey conducted around their coursework. They were also emailed a survey consisting of six open-ended questions related to the industry experience after its completion. Only nine responses were received for the emailed survey. The units of work were assessed for links to the industry experience and STEM connections by the research team (including two of the academics teaching in the course).

Industry partners were interviewed post the trial and the academic staff involved in the trial were also interviewed. All data were de-identified to ensure that there was no connection with the data collection and the coursework. The data were analysed by looking for key themes related to the research questions.

RESULTS AND DISCUSSION

Research Question 1
Initially, when asked about STEM, the majority of the PSTs indicated that it was an acronym and could identify the sub-disciplines and explained and made the connection to
future careers and jobs. Only a few mentioned the interdisciplinary nature of STEM within the context of industry.

Post their industry experience PSTs demonstrated a much greater awareness of the links between the sub-disciplines of STEM and could provide specific instances of examples of STEM observed in their experience. It is interesting to note that their views of STEM appeared to be influenced by their industry experience. For example, if the focus was digital technologies they used very different examples than if their industry experience was in a manufacturing or a food processing industry. This again indicates the complexity surrounding the term STEM.

Research Question 2

When asked about what they had learned from their involvement in the industry experience, the key themes articulated by the PSTs were increased knowledge and skills (STEM careers, discipline knowledge, pedagogical knowledge and 21st Century skills), greater understanding of how the disciplines connect with industry, and how to make real life connections. The quotes below are typical of the type of responses received from the PSTs.

STEM is important because with the advancement in technology, students today are very aware of the life skills they need and the skills they might not need. Subjects like Maths and Science are being misunderstood because students are viewing them as unnecessary. One of the reasons for this is that the applications of these subjects are not the simplified problems that are presented to them in textbooks. (Sylvia)

Help to show the purpose when teaching - students will often engage more or better when they understand the reasons why they need this knowledge (Tim).

Research Question 3

This more sophisticated understanding of STEM in schools was also exhibited in the units of work they developed, throughout which they demonstrated how the STEM activities linked to the science, mathematics, and technologies (including design and technology, and digital technologies) curricula. Also, the strong integration of the industry into the units was evident. The PSTs commented on their improved ability to plan, use hands on activities and make the content more authentic.

I think it will prompt me to make an effort to collaborate with both industry and other teaching and learning areas. It will also give me new things to keep discovering to share with students (Evelyn).

The PSTs also identified that they were more confident in building connections with industry and with STEM in general.

I gained knowledge about the industry, how it operates, how industry partnerships can assist with teaching stem and the career pathways that are available in the industry. A STEM unit around robotics and their use of circuit boards has been developed to coincide with the industry placement, which can be used in a classroom and adapted for differing year levels. I
am now more aware about how to integrate different subjects into a unit and the importance of design and technology aspect of STEM (Alex).

Research Question 4

There were some challenges associated with implementing the project. The challenges highlighted by the PSTs were associated with limited background knowledge of the industry in which they completed their experience; time required by the PSTs to meet, to plan, and to visit the industry they were working with (they were in different classes and so no common meeting time), time of the year in which the industry experience was undertaken as some needed to compete a school placement shortly after the industry experience.

The main challenge for me was that I didn’t have any prior knowledge on electronics. Therefore, at the beginning of the placement I had difficulty understanding what the products were used for, and the purpose of the machines and their operation. (Evelyn)

CONCLUSIONS AND SIGNIFICANCE

The findings of this project support previous research (Gibson, 2013) in the area. The increased confidence of PSTs when connecting to each of the curricula (Gibson, 2013) was a critical component as STEM does not have its own curriculum but is embedded throughout as shown in the ACARA (2016) focus for STEM. The PSTs increased ability to articulate what they mean by STEM teaching and learning was something not described explicitly in previous studies but was an important outcome for the project.

Utilisation of the experience in planning to teach (King, 2015) was exhibited clearly by the PSTs drawing on what they had learnt from the industry placement. Essentially, the industry placement provided the real-world referent around which to structure their teaching while ensuring greater relevance for their students. Furthermore, using this as a context for teaching enabled them to consider additional community resources that might be relevant, as well as raising PST awareness to the benefits of establishing industry connections once they commenced teaching.

Not surprisingly, for each group the concrete examples incorporated into their teaching plans varied based upon the particular industry placement that had been experienced by the PSTs. This is a key finding because only 60% of PSTs (identified in the initial survey) had any industry experience and this was generally retail related, so for the other 40%, this was their first practical opportunity to work within an industry.

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PARTICIPATION IN SMALL GROUP INTEGRATED STEM ACTIVITIES: A GENDER-FOCUSED CASE STUDY

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ABSTRACT

Gender equity issues remain a challenge in STEM, with women underrepresented in STEM fields. As integrated STEM instruction becomes increasingly common in elementary classrooms, it is important to consider whether the small group activities that are commonplace in STEM instruction support the equitable participation of young girls in STEM activities. This study builds on the existing body of literature to better understand how gender is related to student participation in small group STEM activities. A multiple embedded case study was used to explore the experiences of four students in grade five as they participated in the small group portions of an integrated STEM unit. Two male students and two female students worked together throughout the unit to explore science content related to electromagnetism and apply their content knowledge to an engineering design challenge. Video and audio of students’ small group interactions were analysed using an observation protocol. Findings suggest that boys and girls participate in small group STEM activities in different ways, adopting distinct roles within their group. In addition, students displayed different patterns of interaction in science-focused and engineering-focused lessons, suggesting that students need additional practice and support in navigating between science and engineering in integrated STEM units.

Keywords: Integrated STEM, small group learning, gender equity

INTRODUCTION AND GOALS

Recent educational reforms in the U.S. have promoted integrated science, technology, engineering, and mathematics (STEM) as a means of remaining globally competitive and advancing the knowledge and thinking skills of all students (National Research Council [NRC], 2012). Despite efforts to improve the access to STEM opportunities and the quality of STEM education, women continue to be underrepresented in STEM fields (National Science Foundation [NSF], 2017).

As integrated STEM instruction becomes more common in the elementary grades, it is important to understand whether this learning supports the STEM participation of young girls. Small group activities account for almost half of science teaching (Baines, Blatchford, & Kutnick, 2003), but boys and girls engage differently in these science group activities (Jovanovic & King, 1998). However, little is known about whether gender differences in student participation are present in small group, integrated STEM activities.
The present study aims to build on the existing body of literature to better understand how gender is related to student participation in small group STEM activities. This study aims to address the research question: *What differences, if any, are seen in the ways upper elementary boys and girls participate in small group activities during an integrated STEM unit?*

**THEORETICAL FRAMEWORK**

Sociocultural theories serve as the theoretical frame for this research, with the social process of collaboration in the classroom playing a central role in student learning. Knowledge-building practices are influenced by social interactions (Lave & Wenger, 1991; Vygotsky, 1978) and have social consequences (Lemke, 2001). Lave and Wenger (1991) describe learning as a situated process in which learners develop practices that are increasingly closer to the authentic practices of experts. Learners do not initially have access to the skills and knowledge of experts in a given field, so they are only able to engage in authentic practices to a limited degree through legitimate peripheral participation. Because learning takes place through participation rather than simply in an individual’s mind, participation is a precondition for learning. Learning in STEM is a matter of learning both content (science, mathematics, and engineering) and how to participate in STEM communities of practice.

With calls for authentic experiences in the classroom to engage students in science and engineering practices similar to those of scientists and engineers (e.g., NRC, 2012), science teachers are increasingly faced with the challenge of creating authentic STEM communities of practice within the elementary classroom. In this study, an integrated STEM unit provides an authentic, real-world context for learning. As students engage in small group activities throughout the unit, they are involved in the co-construction of their knowledge and practices.

**METHODOLOGY**

**Research Design**

This study utilised a multiple embedded case study to explore the phenomenon of students’ experiences in small group activities during an integrated STEM unit. A case study method was selected because of the desire for in-depth exploration of a social phenomenon and how it works (Yin, 2014). In this study, four students working together in a small group each represent a case; these individual cases were analysed independently, and cross-case analysis revealed both similarities and differences in how the students experienced an integrated STEM unit.

**Context**

This study is situated within a five-year, NSF-funded research project that provided ongoing professional development and coaching for K-12 science teachers in the Midwestern United States. The project focused on helping teachers move toward integrated STEM instruction based on the framework for integrated STEM education (Moore et al., 2014). Teachers participated in professional development and worked in teams to write integrated STEM units that were implemented in their classrooms.

The present study focused on a teacher-developed unit called *Electromagnetic Claw Game: Diggin’ for Fools’ Gold*. It included science content related to magnets and electromagnetism, and students were tasked with designing an electromagnetic arm for a
mechanical claw arcade game. The unit was selected for this study via purposive, criterion-based sampling (Miles, Huberman, & Saldaña, 2014) because of its high-quality STEM integration (Ring-Whalen, Dare, Roehrig, Titu, & Crotty, 2018). Participants in this study were fifth-grade students (two males and two females) who experienced the integrated STEM unit in a mixed gender small group in their science classroom.

Data Collection and Analysis
Data were collected throughout the 14 days of unit implementation. Data sources included video and audio of small group interactions, field notes, and researcher memos. Each researcher focused on one student for the duration of the unit to better understand that individual’s patterns of participation. Researchers took detailed notes while watching small group videos and wrote memos about the students’ participation in each day of the unit. Small group videos were also analysed using an observation protocol to describe student participation in small group activities, including both verbal and non-verbal means of participation. Jovanovic and King’s (1998) protocol, which focuses on science activities, was modified to effectively capture the types of participation that may be seen in integrated STEM activities.

Researchers coded three-minute segments of small group activity, identifying all means of participation a student engaged in during that period of time. Each student received a score of 0 (behaviour not present) or 1 (behaviour present) for every means of participation in every time segment. These scores were summed within each lesson, across science lessons, across engineering lessons, and across the unit as a whole to triangulate findings. Cross-case analysis was used to identify similarities and differences between cases (Yin, 2014), allowing for a broader understanding of gender differences in participation in small group STEM activities.

RESULTS

Case 1: Koob - Scholarly, Designated Leader
Koob (all names are pseudonyms) was a Hmong male and spoke Hmong as his home language. He received English as a Second Language (ESL) services earlier in his education, but he no longer qualified for such services. Koob was a dedicated student who was designated as the group leader. He enjoyed showing off his intelligence, particularly to the various teachers in the room. He was quick to suggest new ideas and answer others’ questions, but he was also quick to give up when challenged with content or tasks he did not fully understand. Koob, although sometimes a bit bossy, focused on being successful in the engineering design challenge no matter what it took, even if that meant controlling the task and directing other students.

Case 2: Ying - Deferential but Engaged Potential Leader
Ying was a Karen female and spoke Karen as her home language. She received ESL services in the past but no longer qualified for language support. Ying was focused, worked to keep her group on task by assisting them even when she was not asked, and accepted whatever roles were delegated to her. She engaged in the hands-on activities, encouraged her teammates, was responsible for record-keeping for her group, and suggested ideas for design improvements. Although she was very involved in the activities, she was hesitant to speak in front of teachers and did not push to make sure her ideas were taken up by her teammates. Ying expressed self-doubt about her intelligence and ability on multiple occasions, but she also defended herself and her female teammate when boys made disparaging comments about them.
Case 3: Cai - Distracted Class Clown

Cai was a Hmong male and spoke Hmong as his home language. He received ESL services in the past but no longer qualified for ESL. Cai was a social student who wanted to be liked. As such, he was more interested in interacting with his group socially than in focusing on science or engineering. He liked to entertain and preferred to spend time distracting his group rather than moving the team forward. He did not want to be the leader but clearly desired the approval of Koob. Cai developed a comradeship with Koob, but he did not actively seek out interaction with either of the girls on his team.

Case 4: Maiv - Invisible but Interested Onlooker

Maiv was a Hmong female and spoke Hmong as her home language. She received ESL services to support her English language development and was approaching the highest level of language proficiency on the district’s assessments. Maiv was by far the quietest student in the group; she rarely engaged in any form of discourse and only voluntarily spoke to Ying when both boys were away from the table. She took her turn when collecting data and occasionally helped to wire the electromagnet, but she also declined to participate when directly asked by a teacher or group members. Maiv was rarely off-task; even when fidgeting with the equipment or doodling, she carefully observed what the rest of her group was doing and always recorded data in her notebook.

Cross-Case Analysis

Engagement

The first portion of the unit focused primarily on science content that would be applied in the engineering design challenge in later lessons. The boys were quick to get involved and manipulate the materials, whereas the girls were slower to warm up and engage with the hands-on materials. When the girls did begin to manipulate the materials, they seemed to mimic the methods of manipulation the boys had already demonstrated. Despite these different patterns in how they worked with the materials, both genders were equally likely to manipulate the materials, with 71 instances of manipulation among the girls and 70 among the boys.

All of the students expressed frustration at some point during the unit. The causes of their frustration, however, were quite different. Ying and Maiv, the female students, were much more likely to become frustrated with a person, expressing such frustration on 16 occasions throughout the unit. The males only showed frustration toward a peer on six occasions. Both male and female students demonstrated frustration directed at a task, with 21 occasions for males and 18 occasions for females.

Science and Engineering Engagement

Collaboration between the male and female students was relatively natural during the science-focused lessons, with students attending to turn-taking and equal involvement in the activities. The highly structured nature of the science investigations, with clear expectations for procedures and number of trials, seemed to be more conducive to equitable participation than the open-ended engineering tasks.

When the unit shifted from science-focused to engineering-focused lessons, the students’ means of participation also shifted. Students suggested more ideas during the engineering lessons (60 occasions versus 13 in science lessons). However, the boys became more controlling of the activities, with more disagreements and displays of control and direction. The females directed peers 17 times in science lessons and 17 times in engineering lessons; the males directed only three times in science lessons but 26 times in engineering lessons.
As the students designed their electromagnet prototype, they expressed more competition toward other groups. The increased urgency related to completing the engineering design challenge resulted in students expressing judgment and frustration more frequently, with 43 displays of frustration in engineering-focused lessons compared to 18 in science-focused lessons. The pattern of increased frustration during engineering-focused lessons was true of both male and female participants.

**Group Roles**

The male and female students took on distinct roles within their small group. Koob was the clear leader of the group, and the boys were more vocal participants in the small group activities. Koob and Cai were also “doers,” initiating activity 23 times (compared to six female initiations) and twice as likely as their female peers to take physical control of the materials (16 occasions of control for males; eight for females). In addition to taking charge of the activities, the male students also took control of the conversations among their group.

In contrast to the boys, Ying and Maiv were less active in determining the direction the group would take. Instead, they frequently observed their peers (93 observations for girls; 55 observations for boys), and took notes. Differences in record-keeping were apparent between genders, with girls record-keeping 74 times compared to 41 times for boys. The record-keeping roles became more distinctly female in the engineering-focused lessons. In these lessons, the team had a single worksheet and Ying was almost solely responsible for filling it out at the direction of Koob. Similar patterns were seen in the girls’ tendency to follow directions of their peers. The girls followed on 11 occasions during science lessons and 20 times during engineering lessons; the males followed zero times during science lessons and only four times during engineering lessons.

Throughout the unit, both boys and girls engaged in directing their peers. They directed in nearly equal proportions (34 for girls and 29 for boys), but their reasons for directing and the outcomes of their directions differed. The girls tended to direct peers in order to stay on task and encourage participation from those who were less involved, particularly during the science lessons. These directions tended to be more social in nature, yet they were less frequently followed. In contrast, directions from the boys tended to be specifically focused on making decisions related to the tasks at hand, particularly during the engineering-focused lessons.

**Gender**

Although the students consistently preferred their same-gendered peers in social interactions, they had unique ways of addressing gender issues within the group. The contrast between Koob and Cai, the two males, was especially stark. Koob interacted with Ying quite frequently, demonstrating his willingness to engage with peers of the opposite gender in order to accomplish the tasks they were given. Koob made very few gendered comments, whereas Cai frequently expressed gendered views about who should engage in certain tasks. Cai directed his language to Koob and referred to his female peers as “they” and “them,” talking about the girls rather than with them, even when they were sitting at the same table. Ying and Maiv clearly perceived the boys to be in charge, commenting about the boys telling them what to do and being rude. Ying made self-deprecating comments; however, when Cai made similar comments, she defended herself and Maiv.

**DISCUSSION**

With small group activities accounting for nearly half of science activities (Baines et al., 2003) and purported to be especially beneficial for girls (e.g., Fredricks, Hofkens, Wang, Mortenson, & Scott, 2018), it is of critical importance to consider whether and how these
activities support STEM engagement and interest among females. The four students in this study revealed important differences in the ways boys and girls engaged in the small group activities of an integrated STEM unit. Consistent with previous research (e.g., Jovanovic & King, 1998), patterns of interaction differed between male and female students in this study. The male students often initiated activity and contributed the ideas that were taken up by the group, whereas the female students were more likely to observe their peers and assist with things like record-keeping.

Although both genders were equally likely to manipulate the materials, many of the girls’ manipulations were in support of what the boys were doing rather than related to taking charge of the activity. Previous researchers (e.g., Jones, Howe, & Rua, 2000) have found that boys tend to have more extracurricular experiences related to physical science than girls. As learners work toward more authentic approximations of expert practices in science and engineering (Lave & Wenger, 1991), increased opportunities to engage in such practices likely affects the degree to which students feel comfortable engaging in small group activities. This was illustrated by Ying and Maiv’s hesitance to get involved in the early lessons.

As other researchers have found (e.g., Abell & Smith, 1994; Irez, 2006), students in this study seemed to possess rigid views of how science is done. Discussion of science content is known to be important for students to develop more complex understandings (Lemke, 1990), but students in this study displayed alarmingly little discussion of science content. Consistent with previous research (e.g., Jiménez-Aleixandre, Rodriguez, & Duschl, 2000; Woods-McConney, Wosnitza, & Sturrock, 2016), they discussed procedures and lesson requirements but very rarely negotiated shared meaning of science content or suggested new ideas related to science.

Interestingly, students’ rigid approach to conducting science experiments seemed to promote equitable small group interactions, with all of the students sharing in the responsibilities of the science-focused lessons. The more open-ended nature of the engineering activities resulted in struggles to negotiate participation. In addition, students’ focus on engineering design criteria and constraints in some cases distracted them from applying science content knowledge in decision-making.

This study suggests that students may experience epistemological conflicts when science and engineering are integrated. They were relatively well-versed in the convergent thinking often emphasised in school science learning, but the divergent thinking required to generate multiple design solutions in engineering was less familiar to them. The girls in particular seemed more prepared to negotiate their involvement in the closed science tasks than in the open-ended engineering tasks. They were better able to anticipate next steps and become involved in the activities, likely due to their prior experience in similar science activities in school.

While the ambiguity of the engineering design challenge caused frustration for all students, the boys were able to take charge and ensure that they continued to participate. Struggles to negotiate the goals of science and engineering are likely to be especially challenging in integrated STEM activities that require students to move between science and engineering.

CONCLUSIONS AND SIGNIFICANCE OF THE STUDY

As integrated STEM instruction becomes increasingly common, several important implications are evident from this study. First, there is an ongoing need to consider students’
early experiences, both in and out of school, to ensure that girls have opportunities to engage in science and engineering practices. The girls in this study displayed initial hesitancy when they were faced with science tasks, and increased opportunities to participate in science activities will increase student comfort. Second, students must be supported in understanding how the disciplines and goals of science and engineering are both similar and different, including how to navigate back and forth between science and engineering challenges.

Finally, in order to ensure that they are equipped with strategies for equitable participation, students need additional practice and support in engaging in less structured small group activities like open-ended engineering design challenges. Both teachers and curriculum developers should consider how to build this support into activities.

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FACILITATING A GENERALISED PERSPECTIVE OF PROBLEM SOLVING IN A STEM ENVIRONMENT

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ABSTRACT

This paper reports on a practitioner action research project investigating how problem solving and using LEGO’s EV3 robot can support students to analyse problems and their solutions from a generalised perspective. The student examples presented highlight how managing a cyclical problem solving process, that includes conscious self-monitoring of the process, can foster advantageous outcomes in a primary classroom. The students were encouraged to build a general way of thinking that grows from their ways of working with the robots and collectively with peers. The results so far suggest that students are able to build general ways of thinking that will lead to them to better manage the problem solving process.

Keywords: Problem solving, LEGO EV3, metacognition and primary school

INTRODUCTION

The research project reported here is intended to highlight a pedagogical approach that supports students to establish generalised ways of thinking about problems and problem solving. This project was designed by two teachers to investigate ways in which problems can be brought to life in order to facilitate a generalised way of thinking about solving problems. The project utilised LEGO’s programmable robot EV3 Mindstorm, Apple’s iPad and the EV3 Programmer App.

Developing a generalised way of thinking about problems and the problem solving process draws on a capacity for students to interact, engage with and link structural generalities and relationships inherent in most tasks. Kieran (2011) suggest that successful problem solvers are more likely to analyse problems, plan responses and review solutions from a relational, structural and metacognitive perspective. They consistently ask themselves and others questions that seek to connect, implement and review relevant concepts, suitable processes and efficient strategies.

Ultimately, successful problem solvers access, monitor and direct what they know and what they do. Both Kieran (2007) and English (2007) state that successful problem solvers consider and consistently analyse relationships among concepts, notice structure, study to understand change, make generalisations and solve problems. Importantly, both researchers also highlight how these ways of thinking are then used to justify, prove and predict new, and ever increasingly efficient solutions to problems. English (2007) explains that through this process ‘numerous questions, issues, conflicts, revisions, and resolutions arise as children develop, assess and prepare to communicate their solutions’.

Alternatively, research (Booker, Bond, Sparrow & Swan, 2014; English, 2007) would indicate that difficulties in problem solving occurs because students have little understanding of the problem and how to manage a problem solving process. Student can simply focus on
getting an answer and lack the capacity to develop a plan when a solution is not immediately obvious. This can lead students to focus on the surface level of a problem – unable to see or understand the inherent relationships among concepts and process. Other issues can include students lacking perseverance in problem situations or consistently adopting inefficient way of working. With this in mind, this action research project seeks to answer the following questions:

1. Can a programmable robot support students’ capacity to move towards a generalised way of thinking about problems and problem solving?

**METHODOLOGY**

Research proceeds in cycles, in which one considers and then reconsiders every aspect of the process. Even within cycles, insights (including those caused by failure or chance observation) may cause a reformulation of underlying perspective, or of what are considered salient phenomena; they may result in new representations, alternative data gathering or new ways of thinking about data that have already been gathered; and new conclusions. (Schoenfeld, 2007, p.72)

This qualitative research used the method of design research (Cobb & Gravemijer, 2008) where observations and registration of student activity by the participant were the prime sources of data. The dataset for this study included work samples from all lessons, digital video and audio records of students’ interactions with peers and their teacher. The study is set in a Year 4 class in an inner-city State Primary School that draws children from a variety of socio-economic and ethnic backgrounds. The school has a commitment to developing learning amongst all students by using and applying the following teaching and learning protocols:

- prioritising high expectations
- emphasising inquiry focussed teaching
- establishing challenging learning tasks
- promoting co-operative group structures and techniques
- employing higher order questioning and
- systematically connecting feedback to the artefacts created by students’

Constant reflection on participant actions, synthesis of both the qualitative and quantitative data generated from these interactions leads to a cycle of enactment, analysis and further design refinement that can allow generalisations about learning based on all the different elements found within classrooms, rather than the laboratory style experiments that exist within other research paradigms (Cobb, Gresalfi & Hodge, 2009).

**SETTING THE SCENE**

The problems the Year 4 students investigated were developed and modified from the LEGO EV3 lesson plan *Autonomous Parking* (LEGO Education, 2017). In the lessons students described, planned and created programs to autonomously parallel park, angle park, perpendicular park, reverse perpendicular park and reverse parallel park the robots between two blocks. Students documented their project using videos and photography.
To develop students’ capacity to move towards a generalised way thinking about problems and problem solving, the teacher implemented a design cycle to better manage the problem solving process. The model, *A Plan to Manage Problem Solving* (Booker et al., 2014; Booker & Bond, 2009) was used to help prompt students to self-regulate, monitor and reflect on their processes and solutions during the robotics lessons. This cyclical plan provided students with a platform to explain both their impediments and successes in solving the problems.

**DISCUSSION**

Each lesson promoted and utilised cooperative group structures where student worked towards a common goal. Theorist such as Lave & Wegner (1991), Cobb & Yackel (1996) and Cobb & Jackson (2015) suggest that a critical component of learning is the process whereby students are integrated into a community of meaningful practice. Importantly, students were encouraged to recognise the connection between what they brought to the group, how they communicated to and interpreted what others were doing, feeling, thinking and believing so as to achieve a common goal or solution.

By communicating their thinking, ideas were collectively challenged, modified and tested with the *LEGO EV3 robot*. The immediacy of the robot’s feedback was initially a positive. Students could develop algorithms to carry out a series of instructions to solve the parallel, perpendicular and diagonal parking problems. However, as the lessons progressed the reversing problems caused some difficulties. It is suggested, these difficulties emerged because students were unable to re-interpret and program the opposing transformations required to reverse park the *LEGO EV3 robot*. The frustrations further manifested itself is such a way that many students did not engage in self-monitoring process a critical component of generalised thinking. Many students simply continued using a try and adjust method, as highlighted by the exchange between the teacher and a group during the lesson:
Teacher: How did you get to the solution?
Sam: Well, we counted the seconds and then changed the rotations to number of seconds and it got to the right place.
Teacher: So, basically, you just kept trying and changing things, is that right?
Lila: Yeah, that’s basically what we did… It took a long time.
Sam: I only arrived at the decision to change the move to seconds right at the end.
Teacher: How do you think you could have arrived at that decision sooner?
Sam: Maybe if we stopped and thought about it more.
Lila: Yeah, I think we should have done that.

At the conclusion of the lesson the teacher discussed and asked the students to explain their difficulties and frustrations. The students explained to the teacher why they were becoming frustrated, as illustrated in the following discussion:

Teacher: What is a strategy?
Taj: It’s like something you do to help you get the right answer.
Teacher: Any other thoughts.
Charlie: Kind of like a plan that you have.
Frankie: Yeah, it’s like a buddy that helps you when you’re challenged.

Teacher: How do you know when you need to use strategies to work out problems?
Zachary: If the problem is complex. Like it has lots of parts to it.
Finn: Yeah, if it’s hard.
Teacher: Right, anything else?
Ella: If you are not sure about it.
Teacher: You mean, like, if you feel confused.
Ella: Yeah.
Charlie: Also, if you haven’t seen a problem before. If it’s something new.

Teacher: How do you know when you need to change strategies?
(students are silent)
Teacher: For example, when you are reading, and you realise that you don’t understand the text, what strategy might you use?
Ethan: Re-read it.
Teacher: Okay, great. What if you read it again and you still don’t understand it?
Are you going to keep on re-reading it again over and over?
Taj: You might just skip it.
Lila: You could look to see if there is a word you don’t know.
Kaldor: Yeah, and try a different word.
Melissa: Or you could go and ask your parents what it means.
Teacher: Right. So you would use a different strategy.

Teacher: So, how do you know when you need to change strategies?
Charlie: When one strategy isn’t working.
Teacher: And how does that feel?
Sam: Like you’re really annoyed.
Ella: Yeah, like frustrating.
To overcome this problem of student frustration and develop the capacity to self-monitor, the teacher established and modelled a series of metacognitive self-monitoring questions. Self-reflection and metacognition are critical in developing a generalised understanding of problem solving (Mayer, 1998). Students were expected to use these questions as they created their LEGO EV3 programs (see Table 1).

<table>
<thead>
<tr>
<th>Metacognitive self-monitoring questions</th>
<th>Preparing for success</th>
<th>Monitoring success</th>
<th>Reflecting on success</th>
</tr>
</thead>
<tbody>
<tr>
<td>- What am I trying to do?</td>
<td>- Am I succeeding?</td>
<td>- Have I succeeded?</td>
<td></td>
</tr>
<tr>
<td>- Have I done something similar?</td>
<td>- Is my current strategy working?</td>
<td>- How do I know I succeeded?</td>
<td></td>
</tr>
<tr>
<td>- What strategy has worked before?</td>
<td>- What other strategy could I use?</td>
<td>- What strategies have I used that may be useful in the future?</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Metacognitive self-monitoring questions

The questions helped to prompt students to look for alternatives as well as resetting, realigning and reassessing their application of their new ideas as part of the problem solving cycle. Importantly, the robots were able to provide feedback about these decisions. From the teacher’s perspective, developing the students’ capacity to self-monitor and see their thinking was critical as they addressed other possible solutions to the reversing problem. Schoenfeld (2016) suggests, when confronted with complex problems, even the most successful students can struggle with self-monitoring of the problem solving process. It is suggested that in conjunction with teacher expertise the EV3 robots helped establish this way of thinking. The immediacy of the robot’s feedback meant students knew when they had developed an appropriate solution or needed to look for alternative solutions.

CONCLUSION

At first glance, The LEGO EV3 programmable robotics task succeeded in providing an opportunity to implement a research based pedagogical approach that established a generalised way of thinking about problem solving outside. All students were highly engaged as they worked with the LEGO EV3 robot to solve authentic, complex problems. The programming task proved to be a highly effective problem-solving context because it provided the opportunity for students to practice making strategic decisions independently and directly experience the results of those decisions. An opportunity not readily found in the mathematics domain, in which students generally rely on teacher judgment to determine success.

The concrete nature of success and failure in robotics programming which forces students to observe the results of their decisions. The immediacy of feedback provides a powerful opportunity for the teacher to highlight the importance of a problem-solving process and the metacognitive skills used to move through it successfully. By consistently applying metacognitive skills while working through a problem-solving process is exceptionally valuable in establishing a generalised way of thinking about problems and problem solving.

It is suggested that these programmable robotics problem solving tasks could play a vital role in the development of a generalised way of thinking as students work through a problem-solving cycle. Furthermore, similarities among mathematics, science, design and engineering cycles can be highlighted to students when working in and across these domains. The reason for conducting such an analysis is to help advance our understanding of what
might be happening in STEM classrooms and more precisely reflecting on the activities of students and teachers. By reflecting on practice there are opportunities to improve pedagogical outcomes.

**REFERENCES**


ABSTRACT
This paper reports the findings from the initial embedding of a process of enhancement and reflection in pre-service teacher (PST) science and mathematics methods units and the influence the process has had on PST confidence. The focus of the embedding was to enhance, through collaboration with practicing mathematicians and scientists, the capacity of PSTs to use local contexts to create situated learning opportunities for their students that would include enhanced scientific/mathematical thinking requirements. The embedding also included a reflective process to enhance PST understanding of the emotional experience of teaching as a means of supporting their sense of confidence and identity. While there were some shortcomings reported by students in the complexity of the process, positive outcomes were reported for both enhanced mathematics and scientific thinking and in PST confidence through reflection.

Keywords: Mathematics education, science education, initial teacher training, enhancement, reflection

INTRODUCTION

Tertiary and secondary school mathematics and science in Australia has faced a number of challenges in recent years, including a drop in the participation rate (Chubb, Findlay, Du, Burmester, & Kusa, 2012), a lack of suitably qualified teachers, particularly in rural and regional areas (Australian Academy of Science, 2016), and a substantial attrition rate of teachers within the first five years of their employment (Buchanan, Prescott, Schuck, Aubusson, & Burke, 2013).

A recent focus on improving the science, technology, mathematics and engineering (STEM) educational outcomes has resulted in strategic responses to such challenges funded by the Australian Government. One such initiative was the project: It’s part of my life: Engaging university and community to enhance science and mathematics education (IPOML) (https://www.scu.edu.au/school-of-education/collaborations/its-part-of-my-life), commenced in 2013. The project aimed to improve mathematics and science education through developing strategies to enhance pre-service teacher (PST) education based upon enhancing subject content and pedagogical teaching strategies and improving understanding of the emotional experience of teaching.
This paper reports on the development and embedding of a novel strategy in online science and mathematics pre-service teaching methods units. The strategy was implemented to improve the enhancement of science and mathematics teaching through collaboration between PSTs and scientists or mathematicians employed in the workplace and through improving PST understanding of the emotions experienced when teaching. The enhancement process was intended to improve teaching quality by making lessons more strongly based in local, real-world contexts emphasising mathematical and scientific thinking. The paper reports findings from a survey of the first cohort of PSTs who completed the units and concludes with a discussion of the potential benefits of the strategy to science and mathematics educators.

THEORETICAL FRAMEWORK

Science and Mathematics Thinking in Context

In contrast to the view of many educators, scientists and mathematicians, traditional teaching approaches are characterised by being teacher-centred and didactic in nature, where the teacher, as the font of knowledge, presents the students with content that must be learnt (Cope & Kalantzis, 2010). Science and mathematics, however, should be taught “as it is practiced, in ways that engage students, encourage curiosity and reflection, and link classroom topics to the ‘real world’” (Office of the Chief Scientist, 2014, p. 23). This places a focus on science as an inquiry-based endeavour which investigates and seeks explanations for real-world phenomena utilising the methodologies of real world scientists. Real-world contexts have been used as the approach to set assessment items in the Programme for International Student Assessment (PISA) (Fensham, 2009) and as the rationale for the current NSW years 7 to 10 Science syllabus. Such contexts may assist students in developing personal meaning in relation to the underlying science and mathematics that is being addressed (Anastopoulou et al., 2012; Calder & Brough, 2013).

Identity and Emotions during Teaching

Identity theory (e.g., Stets & Serpe, 2006) identifies a relationship between role performance, emotions and the level of commitment to identity—an individual’s sense of identity, once established, is robust and will resist change (Burke, 2006). In situations where an established identity is inappropriate in the face of circumstances, change is resisted and adaptation will occur only when necessary to accommodate the circumstances giving rise to the identity challenge. If a PST or early career teacher encounters confronting and negative experiences while teaching, identity theory proposes that the negative emotions generated may reduce the commitment the individual has to his/her teacher identity. This is compounded by the lack of time that many PSTs have had to form a robust sense of identity capable of coping with setbacks and challenges. In this situation, it is possible that the PST will reject the identity associated with being a teacher and will discontinue study. It has also been argued that teaching confidence is associated with the level of emotional arousal when PSTs are engaged in teaching (Tobin & Ritchie, 2012). It is essential, therefore, that PSTs appropriately understand their emotional responses when teaching in order to persist in the face of challenging teaching situations and to maintain their sense of identity, interest and confidence in the classroom (Yeigh et al., 2016).

The Enhancement-Lesson-Reflection (ELR) Process

The Enhancement-Lesson-Reflection (ELR) process was developed as a part of a broader IPOML project, undertaken across the Australian Regional Universities Network (RUN) (Woolcott et al., 2017a, 2017b, 2017c) and developed around a model derived from teacher education processes related to a collaboration nexus, previously described for
Australian contexts (Cook & Buck, 2013). The ELR process, developed and trialled within IPOML, was designed to develop the competence and confidence of pre-service teachers in engaging with and inspiring classroom science and mathematics learners. The ELR process shows pre-service teachers how to use the science and mathematics of their locality to solve science and mathematics problems around them by collaborating with university and community experts. Figure 1 illustrates the ELR process and the potential for iteration.

![Diagram of the Enhancement-Lesson-Reflection (ELR) process illustrating iterative capacity](image)

Figure 1. The Enhancement-Lesson-Reflection (ELR) process illustrating iterative capacity

As part of the implementation of the ELR process in the diverse environments typical of regional and remote learning, two embedded trials were completed in 2015 in the online pedagogy units MATH2 (7-10 Mathematics) and SCIENCE2 (7-10 Science) of a single university. Online instructional modules (available from the corresponding author) were included for both units containing the various resources that have been developed to support:

- Teaching in a local context;
- Enhancing engagement with mathematical/scientific thinking through collaboration with practitioners and educators;
- Reflection on teaching and the role of emotions in perceptions of teacher confidence and competence.

Both units included an assessment task involving the enhancement and reflection adapted from the ELR process. The sequence for the tasks may be summarised as follows.

- The SCIENCE2 task commenced with an existing 10-lesson sequence that addressed a specific aspect of the syllabus and had been submitted as an assessment task in a prerequisite methods unit, SCIENCE1. The MATHS2 task involved the development of a new 3-lesson sequence;
- The students developed some initial ideas about how the sequence might be taught. In the case of SCIENCE2, these ideas were able to be based on feedback provided by the marker in the previous unit and on their own intervening teaching experience;
- Communication was initiated by each student with a mathematics/science specialist to enhance understanding of the underlying thinking as well as possible practical contexts for applying that thinking;
- Communication with a practicing mathematics/science educator in relation to how teaching pedagogy might be improved and the ideas from specialist might be incorporated;
• The lesson sequence was written to incorporate enhancements in the sequence, with a focus on the use of local contexts to ensure situated learning opportunities for students and the enhancement of the underlying thinking involved;
• A full lesson plan was written for one lesson;
• The planned lesson was taught to school students and recorded on video;
• A video-stimulated reflection as described in the resource materials was then completed by each PST with a view to identifying critical moments during their teaching, identified by positive or negative feelings experienced while teaching;
• Reflection was completed on each critical moment with a view to understanding how and why these moments occurred, how confidence/competence was influenced and the steps that were possible to manage the situation in the future.

METHODOLOGY

The study gathered qualitative data from an end-of-unit survey and quantitative data from unit evaluations. Students enrolled in the units MATH2 and SCIENCE2, voluntarily participated in the project allowing researchers access to their assessment tasks and their evaluations of the unit. The SCIENCE2 task was completed by 65 participants, and MATH2 task by 28 participants.

RESULTS AND DISCUSSION

Feedback from PSTs indicated that some found the tasks to be quite involved, particularly the number of steps to be accomplished over an extended time frame, as illustrated in the following comments.

Possibly the assignment notifications. If it wasn't for the explanations by Dr *** of what he expected in assignment 1 in particular, I am fairly sure I would not have the expected requirements.

Although the first assessment was very beneficial it took an immense amount of time. The final assessment task was very challenging, however provided an excellent opportunity for reflection and skill development.

While the size of the task was a challenge to some students, the unit evaluations did not indicate that this was a substantial problem, as shown in Figure 2.

![Figure 2. Student evaluations of the overall amount of work required in the units](image)

The following comments are typical of those provided by participants on these tasks and illustrate the outcomes that engagement with the task provided.
Mathematics comment

Through the enhancement process I was able to discover and implement a range of teaching strategies and ideas that I had previously given no thought to. This positive experience of seeking advice from other individuals who work in the fields of education and mathematics has encouraged me to reach out to fellow co-workers and mentors for assistance so that I may continue to improve my teaching. ...The reflection process has shown me just how much I can learn from videoing myself teaching a lesson, watching it and reflecting on it. Whilst I was aware of the benefits of reflection as determined by lecturers and texts, I had not yet actively engaged in ‘watching myself teach’.

Science comment

I went into the enhancement interview with the expert nervous and skeptical. I wasn’t sure what I’d ask, or what an expert could tell me that would be useful in helping me teach students basic concepts. But it ended up being great! Chatting with the expert made me really think about what the basic outcomes I was hoping to achieve with the lesson were, and how these concepts linked together. Before talking to the expert, I realise now that didn’t really think of the key concepts in sequence, and how it’s important that students grasp one before they can grasp the next.

These comment samples support the stance that this ELR process adaptation had the potential to have a substantial impact on student learning.

An examination of the usage logs of the enhancement and reflection content modules in Moodle across both units indicated that the enhancement module was accessed a total of 613 times, while the reflection module was accessed just 233 times. These content modules were available from the same page in Moodle and were located together. If these usage rates are an indicator of the value that students placed on the content, it appears that enhancement of teaching was considered much more important than reflection. The relatively low access rate for the reflection module indicates that future iterations of the unit will need to ensure measures are taken to promote student engagement with reflection. Considering the importance of reflection in improving teacher practice (Marcos, Sanchez, & Tillema, 2011) and the focus self-assessment and reflection have within the Australian professional teaching standards maintained by AITSL, it is considered that this area warrants further research in relation to pre-service teacher attitudes towards reflection and their uptake of strategies that prepare them in this regard. This appears particularly important in the context of distance learning, where the capacity to influence students in their allocation of time resources and effort is more limited and students have the capacity to engage with content as they deem appropriate. The unit evaluations for the quality of the resource materials are shown in Figure 3.

![Figure 3. Student evaluations of unit resources](image-url)
The overall evaluations of the units are shown in Figure 4. The overall student evaluations indicate that the majority of students reported a high level of satisfaction with the units.

![Figure 4. Overall student unit evaluations](image)

The evaluations indicate that, while most students were satisfied with the resources provided, the resources would benefit from further development, as would be expected after an initial trial. Feedback from the academic who marked the assignments in both MATH2 and SCIENCE2 indicated that there was a marked difference based upon whether or not the student had engaged with the resource and support materials provided in Moodle. A subsequent comparison with face-to-face embedded trials (Woolcott et al., 2017c) supports this view.

**CONCLUSION**

While the assessment task appears too lengthy in its current form, the process of enhancement and reflection on teaching that it encompasses appears to provide PSTs with a complete experience of the teaching cycle. The requirement to use a previously developed unit and to enhance it with input from colleagues who are more experienced and knowledgeable in terms of content and pedagogy appears as a very valuable exercise. The comments provided by PSTs in relation to enhancing scientific and mathematical thinking through the use of real world contexts appear to support the view proposed many years ago by Lowery (2002). Of particular interest is that some PSTs did not initially see value in the enhancement process, and it was not until they had communicated with the specialists and experienced the potential for improvement in their own thinking and the pedagogical possibilities that they saw the process as a useful one. This situation may be based upon their own experiences of school education, particularly in mathematics, where they were taught in a teacher centric, didactic and content driven classroom.

The importance of reflection as a means of attaching meaning to the emotional experience of teaching was described. One student’s statement that she “found the reflection useful to identify specific occurrences in the lesson and think about how I could have handled them differently, rather than having a vague sense of incompetence. These reflections will also inform my future planning” illustrates the importance of reflection in bringing into focus the emotions that arise during teaching and how this assists PSTs in terms of their confidence at the time and their capacity to prepare for situations in the future. However, the lack of engagement with the unit content relating to reflection is an area of concern. While there are challenges with the complexity of the task that will need to be addressed, perhaps through breaking it down into smaller components, there appears to be great benefit in the
enhancement and reflection process as a means to build more confident and reflective science and mathematics teachers.

REFERENCES


ABSTRACT

With the development of technology, educational teaching methods have become more and more colourful. Among them, gamification learning has attracted the attention of educational scholars and researchers around the world. The purpose of this study is to investigate the effect of immersive learning in STEM and to analyse the learning outcomes and learning attitudes of secondary school students. This study designed a STEM educational activity based on gamification learning, using a quasi-experimental design with a single set of pre- and post-test (N=27 Chinese secondary school students) for a duration of one month. Qualitative and quantitative analysis of the results, the main conclusions are the following three points: (1) students’ scientific knowledge and scientific learning attitudes have been improved significantly; (2) There are significant improvements of students’ confidence with technology and Attitude towards use technology for learning Science; (3) Students can complete the work according to the general process of engineering design and use the basic knowledge of geometric mathematics.

Keywords: STEM, Gamification Learning, Quasi-experimental Research

INTRODUCTION

STEM is a combination of science, technology, engineering, and mathematics. STEM education is not simply a mash-up of science, technology, engineering and mathematics, but through the comprehensive training and application, develops students’ interdisciplinary thinking and improves students' comprehensive practical ability and innovative spirit (Yu & Hu, 2015).

Kelley and Knowles (2016) proposed a pulley block model for integrating conceptual framework of STEM education to help students learn and apply STEM content. During this model, science inquiry, technological literacy, mathematical thinking and engineering design work as pulley, situated STEM learning as the foundation of pulley ascending, the theme problem in the field of practice as a rope, working together to form a pulley block. And all parts must coordinate to show the efficiency of the whole system (Kelley & Knowles, 2016). Situated STEM Learning allows students to construct knowledge in the learning process. 

Situated learning is often used in learning activities supported by science and technology, enabling learners to learn in the knowledge environment constructed by learning topics, and focuses learning activities on problem-solving skills. Robertson and Howells's exploratory study of role-playing game design found that students' independent game production can form a powerful learning environment and can fully utilize subjective initiative and broad thinking (Robertson & Howells, 2008).
This study attempts to use gamification learning to provide a scaffold for situational learning, explores the effects of blending gamification learning in STEM, and analyses the learning outcomes and learning attitudes of junior middle school students.

GAMIFICATION LEARNING

Gamification learning has attracted the attention of educational scholars and researchers around the world. Gamification learning has been applied in science, information technology, physics, English, mathematics, languages and many other disciplines (Sung & Hwang, 2016). Generally, gamification learning is applying game design elements into non-game situations, thus leveraging game elements to promote learner’s motivation and problem-solving skills (Deterding, Dan, Khaled, & Nacke, 2011).

There are currently three main modes of implementation for gamified learning: (1) the use of existing educational games and the use of existing educational elements in the game; (2) researchers design educational games on their own, and educational game is a game where learning is the major goal; (3) Students develop games independently to improve their problem solving, programming, and game design capabilities (Bao & Zhao, 2015).

Vos, Meijden, and Denessen (2011) uses the site (www.memoryspelen.nl) to study the effects of two different interactive tasks on intrinsic motivation and deep learning. 235 students from four elementary schools in the Netherlands took part in a study, one group of students (N=128) made their own Drag and Drop game on the site, and another group of students (N=107) played the existing Drag and Drop game on the site.

The results suggest that making a game may be a better way to improve students' intrinsic motivation and learning effects than playing existing game (Vos, Meijden & Denessen, 2011). Students' independent game production can be regarded as design education, and design education is a form of constructivist learning. This type of education is also known as “learning by doing”. This study allows students to independently make their own game.

DESIGN AND IMPLEMENTATION OF PEDAGOGICAL ACTIVITIES

Teaching Tools

Scratch is a graphical programming software designed for children over eight years old which drag and drop sentences into the script area to complete the programming content in a way similar to the accumulation of building blocks.

Scratch software is not only a tool for programming, but also provides a space for learners to develop ideas and realise ideas, so that learners can enjoy the design and creation process. The Scratch project is very diverse and includes video games, interactive communications, science simulations, virtual tours, birthday cards, etc. (Resnick et al., 2009).

STEM element analysis

The STEM elemental analysis of STEM educational activities based on gamification learning is shown in Table 1.
### Table 1. STEM Element Analysis of STEM Educational Activities Based on Gamification Learning

<table>
<thead>
<tr>
<th>Science</th>
<th>Technology</th>
<th>Engineering</th>
<th>Mathematics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear propagation, reflection, and refraction of light</td>
<td>Application of Scratch</td>
<td>Analyse the function of the game</td>
<td>Geometric Mathematics</td>
</tr>
<tr>
<td>State of matter</td>
<td>Design game prototype diagram</td>
<td>Game testing</td>
<td>Operation ability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improve the game</td>
<td></td>
</tr>
</tbody>
</table>

### Instructional design

Teachers introduce activity themes by demonstrating common maze games and ask students to create a new maze game related to optical knowledge - *Rescue The Light*. The instructional design process (As shown in Table 2) for this study includes five teaching stages: pre-analysis, game design, game development, game testing, and game improvement.

### Table 2. Instructional Design Process

<table>
<thead>
<tr>
<th>Pre-analysis</th>
<th>Analyse the function of light.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game design</td>
<td></td>
</tr>
<tr>
<td>• Design the prototype of the game;</td>
<td></td>
</tr>
<tr>
<td>• Design maze;</td>
<td></td>
</tr>
<tr>
<td>• Place tools of different shapes and shapes to help the small light out of the maze.</td>
<td></td>
</tr>
<tr>
<td>Game development</td>
<td>The game designed will be implemented in Scratch software.</td>
</tr>
<tr>
<td>Game testing</td>
<td>Students conduct game tests on their own and improve on issues.</td>
</tr>
<tr>
<td>Game improvement</td>
<td>The classmates tried each other and evaluated each other's games. After the game is complete, it will be displayed and reported.</td>
</tr>
</tbody>
</table>

### RESEARCH METHODS

#### Research Design

In this study, a single group of pre- and post-test experiments was conducted. The study consists of four courses, each course is 1 hour and 20 minutes. The specific research process is shown in Table 3.

### Table 3. Research Design Process

<table>
<thead>
<tr>
<th>Pre-test</th>
<th>Test Manipulation</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>● scientific knowledge</td>
<td></td>
<td>● scientific knowledge</td>
</tr>
<tr>
<td>● scientific learning attitude scale</td>
<td>STEM Educational Activities Based on Gamification Learning</td>
<td>● scientific learning attitude scale</td>
</tr>
<tr>
<td>● Confidence with technology scale</td>
<td></td>
<td>● Confidence with technology scale</td>
</tr>
<tr>
<td>● Attitude towards use of technology for learning Science scale</td>
<td></td>
<td>● Attitude towards use of technology for learning Science scale</td>
</tr>
<tr>
<td>● Teacher and student interviews</td>
<td></td>
<td>● Teacher and student interviews</td>
</tr>
</tbody>
</table>
**Research object**

The research object is 27 students of a seventh grade in middle school, including 14 boys and 13 girls. The course was conducted in the computer lab of the experimental school.

Each student had a computer with Scratch software. The entire course is taught by researchers. Research subjects have studied the basics knowledge of optics before the study, including the linear propagation, reflection and refraction of light. Prior to the study, the researchers explained 8 hours of Scratch-related knowledge in the information technology class, so it can be considered that most of the research subjects can complete the game production.

**Research Tools**

The scientific knowledge (SK) test papers are jointly discussed and written by researchers and researchers' instructors. The test volume consists of related optical knowledge, such as light propagation, reflection, and refraction. The scientific knowledge (SK) test papers are divided into three dimensions: learning comprehension (LU), knowledge transfer (KT), and graphing ability (DA). The total score is 120 points, and each dimension is 40 points.

This study uses the Physical Attitude Scale (PAS) designed by Kaur & Zhao (2017) to measure changes in scientific attitudes (SA), using Likert's five-point scoring method to make students choose from [very disagree to strongly agree] based on the topic. PAS has five dimensions: enthusiasm toward physics, physics learning, physics as a process, physics teacher, physics as a future vocation (Kaur & Zhao, 2017).

This study uses The Mathematics and Technology Attitudes Scale (Pierce, Stacey, & Barkatsas, 2007) to measure the change of Confidence with technology (TC) and Attitude towards use of technology for learning Science (ST), using Likert's five-point scoring method to make students choose from [very disagree to strongly agree] based on the topic. The investigator revised the MTAS questionnaire and analysed the pre-test of ST and TC scale. The Cronbach’s alpha coefficient reached 0.81, so the questionnaire modified by the investigator had high reliability.

According to the characteristics of the curriculum, the researchers designed a learning sheet for the optical game design course. During the activity, the research subjects used it to design the optical game production in advance and recorded the improvements in the game production process.

The interviews outlines were prepared by the researchers themselves and revised after consultation with the experts. Teacher interviews are used to understand the current state of physics teaching, and the physics teacher's perception of physics learning based on scratch-based optical game production. Student interview syllabus are used to understand the learning experience before and after the study, the evaluation of the curriculum and the learning effect.

**Data Analysis**

Students completed the scientific knowledge test volume, scientific learning attitude questionnaire, Confidence with technology and Attitude towards use of technology for learning Science before and after the course. The collected data were analysed using SPSS22.0 statistics. The analysis software was used for descriptive statistical analysis and paired-samples T test, and the significance level was set to .05. After the study, the content of the study papers, interview records, game works, and classroom observations were analysed, and the effect of STEM activities based on gamified learning on student learning effectiveness and learning attitude was analysed from multiple dimensions.
RESULTS

Science
Table 4 shows descriptive statistics and t-test results of students’ pre- and post-test scores on Scientific Knowledge Test (SK) and Scientific Learning Attitude scale (SA). Students' understanding of scientific knowledge (SK) did not increase significantly (P=.635), but knowledge transfer increased significantly (P=0.022), and graphing ability improved significantly (P=.005). Students’ scientific knowledge (SK) has significantly improved overall (P=.024).

Therefore, based on the students' understanding of optical knowledge, STEM educational activities based on gamified learning are very helpful for students' knowledge transfer and drawing capabilities of optical knowledge. The student's scientific learning attitude (SA) has significant improvement overall (P=.024), and STEM educational activities based on gamified learning have a positive influence on students’ attitudes to science learning.

Table 4. Descriptive statistics and t-test results of students’ pre- and post-test scores on SK and SA

<table>
<thead>
<tr>
<th>Factor</th>
<th>Variables</th>
<th>Before treatment</th>
<th>After treatment</th>
<th>t</th>
<th>df</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>SK</td>
<td>LU</td>
<td>27.91</td>
<td>8.29</td>
<td>28.36</td>
<td>6.53</td>
<td>2.45</td>
</tr>
<tr>
<td></td>
<td>KT</td>
<td>20.57</td>
<td>8.12</td>
<td>21.89</td>
<td>7.40</td>
<td>2.44</td>
</tr>
<tr>
<td></td>
<td>DA</td>
<td>17.32</td>
<td>8.26</td>
<td>20.04</td>
<td>7.84</td>
<td>3.06</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>66.25</td>
<td>20.93</td>
<td>69.82</td>
<td>21.30</td>
<td>3.39</td>
</tr>
<tr>
<td>SA</td>
<td>Total</td>
<td>73.75</td>
<td>9.59</td>
<td>76.61</td>
<td>8.50</td>
<td>2.16</td>
</tr>
</tbody>
</table>

Technology
Table 5 shows the descriptive statistics and t-test results of the before and after test scores for Confidence with technology scale(TC) and Attitude towards use of technology for learning Science scale(ST). Students’ TC and ST both have significantly improved (P=.002; P=.000). STEM educational activities based on gamified learning have a positive influence for students' Confidence with technology (TC) and Attitude towards use of technology for learning Science (ST).

Table 5. Descriptive statistics and t-test results of students’ pre- and post-test scores on TC and ST

<table>
<thead>
<tr>
<th>Factor</th>
<th>Before treatment</th>
<th>After treatment</th>
<th>t</th>
<th>df</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TC</td>
<td>15.32</td>
<td>2.06</td>
<td>16.93</td>
<td>2.04</td>
<td>3.49</td>
</tr>
<tr>
<td>ST</td>
<td>13.36</td>
<td>2.11</td>
<td>16.43</td>
<td>1.87</td>
<td>6.20</td>
</tr>
</tbody>
</table>
Engineering and Mathematics

Before using Scratch to make a game, students have to use a learning sheet to draw a game prototype map, including a precise optical path map. The game design diagram accompanies the entire game design process. The student's game prototype diagram (Figure 1) mainly contains light linear propagation and light reflection knowledge. In order to make the game more informative, the research subjects will actively explore physical knowledge. The communication and share among students contributes to the iterative improvement of the game works, but also can learn the advantages of other students, and finally through the game testing process can be integrated to complete their own works.

Students’ works have their own characteristics, but they integrate as much optical knowledge as possible. In the game work (Figure 2), two or more states are used, such as water, glass, etc. (objects of different colour and shapes), so as to realise the effects of linear propagation, refraction, and reflection of light, and basically combined the geometrical knowledge of mathematics, such as squares, diamonds, triangles, rectangles and other shapes, and will use 30, 45, 60, 90 or other easy-to-calculate angles, this way can simplify the process of game making and checking.

![Figure 1. Game work example (right)](image1)

![Figure 2. Example of a learning sheet (left)](image2)

Interview results

A junior high school physics teacher agrees with the curriculum of this study. He believes that STEM educational activities based on gamified learning can better help students understand scientific knowledge and promote the conceptual change of scientific knowledge, and believe that gamified learning methods can stimulate students' interest in learning.

Students believe that Scratch-based optical game production is helpful for learning optical knowledge, because the process of making games requires the optical knowledge, and the correct angle of calculation is also needed to help light walk out of the maze. Students are more willing to discuss with their classmates during the game production process, and they can also learn while discussing with the classmates and playing each other's games. students agree that learning based on the use of game production is more fun than the traditional classes, and the application of more optical knowledge will make the game more interesting.

CONCLUSION AND DISCUSSION

The purpose of this study is to explore the impact of STEM education based on gamified learning on student learning effectiveness and learning attitude. The conclusions are as follows.
First, students’ scientific knowledge and scientific learning attitudes have improved significantly. The reasons are as follows: (1) Barron and Darling-Hammond (2008) believe that students must learn basic knowledge and develop corresponding skills before they achieve their own ideas and perform corresponding learning tasks. Students have already studied the knowledge of optics and Scratch before making optical games. (2) Robertson and Howell (2008) believe that students’ independent game production can form a powerful learning environment and can fully exert their subjective initiative and broad thinking. Scratch’s learning process can promote teamwork and communication and develop students’ logical thinking skills. Students in the optical game production process can promote learning initiative, learning participation, learning motivation and deep learning through cooperation and exchanges with classmates. (3) Students can continuously review, use, and test knowledge that they did not understand during game production. The process of designing game prototypes by drawing the optical path map on the learning sheet and making the game in Scratch is a review and migration of the optical game. The physics teacher also stated that the optical knowledge is relatively abstract. Students can visualise abstract things through gamification learning, and can help students learn and promote the conceptual change of knowledge better.

Second, students’ confidence with technology and attitude towards use of technology for learning Science have improved significantly. During the game production process, students found that the knowledge of Scratch software can be used to create their own games and learn physics. As a result, students’ technical confidence has improved significantly. From the measurement of attitude towards use of technology for learning Science (ST), most of the students like to use information technology to study physics, and believe that the optical game can be used both in brain and knowledge.

Third, from the students’ worksheets and works, it is found that students can complete the work according to the general process of engineering design and can use the basic knowledge of geometric mathematics.

The purpose of this study is to explore the impact of optical game production on student learning effectiveness and learning attitude. In the future research, we can continue to pay attention to the differences between more disciplines and different learners. It is suggested that future design related STEM project courses can increase the number of samples and randomly selected samples of participating students.

REFERENCES


ABSTRACT

Environmental education among adolescents can help them establish consciousness of environmental protection and keep in better health. The frequent occurrence of smog in China has caused great harm to people's physical and mental health, especially adolescents with weak immunity and little awareness of how to protect themselves. Hence, following GBL theory, we developed a smog-themed educational game application that combines math and science knowledge selected from higher-grade stages of primary school to enrich students’ environmental knowledge background as a supplement for the absence of relevant courses. In the game, students need to interact with None-Player Characters (NPCs) to promote the development of the plot. All the knowledge we have prepared will be presented in the forms of conversation, pictures and options with instant interactions and tests. Different choices will lead to different results. A software evaluation was adopted through a questionnaire and an interview. The questionnaire and experimental observation results indicate that the immersion and stickiness of the game is high, which means learning through this application does enhance students' interests in learning. Through separate in-depth interviews, we also received some suggestions for improvement, such as abridging text and adding some more appropriate animations to give students a better understanding.

Keywords: Smog, environmental education, Game based learning, mobile learning

1. INTRODUCTION

As an important part of human-oriented education, environmental education plays a prominent role in education reform. Its ultimate objective is to cultivate the public’s environmental consciousness and assist in building a sustainable society.

Looking back through history, the industrialisation process in many countries has posed a non-negligible threat to the ecosystem in varying degrees. In spite of significant achievements obtained, environmental problems have gradually become obstacles for social development. A recent study (Varela-Candamio, Novo-Corti & García-Álvarez, 2018) focused on revealing the mechanisms behind people’s environmental, indicating that human behaviour plays a critical role in protecting the environment.

Besides, many other researchers have also found that the promotion of environmental awareness’ affects ecological conservation (Zhang, 1994). When it comes to those countries that have made progress in environmental education, both theoretically and practically, it is natural to find their similarities in education reform: first implement environmental education
and make it part of the existing education system, and then make an overall shift to sustainable education (Li, 2017).

Different areas vary widely in physiographic conditions, social-economic conditions, and human-environment relationships, so their environmental problems show regional characteristics separately. By analysing the human-environment relationships, the essence of a specific area’s pollution issues can be clearly ascertained, which promotes a more accurate understanding of the occurrence of relevant environmental problems (Chang, 2017). Students need to understand the current environmental situation around them in the process of learning environmental knowledge.

For example, industrial production, automobile exhaust, environmentally unfriendly heating methods and many other factors have combined to give rise to smog in Beijing. In addition to these factors, less active cold air movement has resulted in a lack of pollutant dispersion. Consequently, the formation rate of smog in Beijing’s autumn and winter is greatly increased, which seriously affects the physical and mental health of local people. From this perspective, smog education is an indispensable part of environmental education in Beijing.

The rise of mobile learning has led to more forms of knowledge transmission, bringing new prospects to the development of science education. Some scholars define mobile learning as a new type of digital learning in which learners use portable digital devices such as mobile phones to communicate and collaborate with others with the help of wireless communication networks for processing and transmitting information. It can offer a broader and deeper level of interaction compared to all the functions of traditional learning media (Li & Xie, 2015).

In addition to the auxiliary effect on normal learning, the mobility and situational characteristics of mobile learning determine that its most appropriate application area is non-formal learning (Zeng, 2009). In the application of informal learning, how to improve the attractiveness of mobile learning resources is a major research focus. In recent years, according to some forward-looking reforms in areas such as business and education, gamification, which aims to increase participation or encourage certain behaviours, naturally has become the best entry point (Shi & Chen, 2016). Therefore, more and more researchers at home and abroad are trying to support the teaching of the 21st century knowledge through the form of educational games.

The ultimate goal of our project is to enable students to improve their participation and acquire environmental knowledge through games. Based on GBL theory, we have developed an educational game for students from grade 4 to grade 6 in primary school to develop a knowledge of the science and mathematics related to smog, meanwhile also serving as a supplement for the relevant courses in Chinese primary schools.

2. DEMAND ANALYSIS

Education is one of the most important measures of environmental protection in modern society. However, the existing environmental education resources are far from enough to meet the demand, in terms of both quantity and quality. The frequency and severity of smog in China is much higher than that in foreign countries, so it is not practical to use relevant education resources of other countries for reference. In addition, by analysing the domestic smog software market, we found that most existing products lack educational values.
In this context, our project aims to develop a smog-themed game application. There are three reasons why we chose students in the fourth to sixth grade as participants. Firstly, China is vigorously carrying out science education at the elementary education stage at present. Students’ learning experience that have already been obtained in classroom can be regarded as the original knowledge reserve, which provides a more accurate estimate of the individual’s original level for the assessment of the effectiveness of game development. To combine the science direction of the game with the environmental hotspot, we decided the final content according to the curriculum standards at the first stage of this study. Secondly, environment education helps pupils to comprehend the idea of sustainable developing concept. Thirdly, chronic exposure to smog increases the risk of cardiovascular disease, so it is of great significance for the new generation to master basic self-protection measures.

3. RESEARCH OBJECT AND CONTENT

3.1 Research Object

- Develop an education game based on cognitive theory, multimedia teaching theory and Game-based Learning theory.
- Test the knowledge mastery of students after using the game, according to practical applications and case studies.
- Discuss the feasibility of learning by integrating science textbook knowledge and game elements.

3.2 Design and Develop PM2.5 Application

3.2.1 App Function

Based on the characteristics of students’ cognitive development, the specific design idea refers to the three points proposed by Ma and Wang (2011): Player Position, Narrative and Interactive Design. We hope to design an education game for players to gain knowledge about smog by creating specific situations. Through dialogue between the protagonist and NPCs, pictures, Q&A and other interactive forms, we convey the definition of smog, the cause of smog’s formation, the impact of smog on the human body, protective measures, and other related knowledge, with specific situations. Our scene is close to life, equipped with easy and humorous music. In our game, Q&A mode is used to get feedback instantly, which can better help the players to absorb knowledge.

Through this game, players can learn about several knowledge points like how smog forms, the difference between smog and fog, how to select a proper mask to protect themselves from smog, initial selection of air purifiers through simple indicators, and so on.

3.2.2 Integration of New Curriculum Standard Knowledge

Our educational game aims to combine scientific knowledge about smog with the knowledge that elementary school students in grades 4-6 are now learning in their textbooks. Hence, we focused on math and science textbooks published by the Beijing Normal University press and PEP. After matching and summarising, we extracted knowledge points that might be related to the knowledge of smog, and gave them to the teachers of related disciplines to check. After confirming that there were no mistakes, we started to draw our knowledge outline.

The math topics selected mainly included the understanding and confirmation of decimal numbers, while the science included material science (air, light, heat, etc.), life science (humans’ life activities, etc.) and earth and space science.
Knowledge points from the three grades are shown in Figure 1 to Figure 3.

Figure 1. Knowledge points in grade four

Figure 2. Knowledge points in grade five

Figure 3. Knowledge points in grade six

3.2.3 Game Script Writing

In the game, players will be our protagonist Ai Bao. She needs to complete all the relevant tasks in the map at the six locations —— park, school, hospitals, home, observatory, and restaurant.

Each location corresponds to a certain main line task, and players need to trigger the specific task and complete it. When all the tasks in the six scenes are over, the game is cleared.

Taking the hospital scene as an example, we list the scripts and related knowledge points as detailed in Table 1:
Table 1. Game script and knowledge points

<table>
<thead>
<tr>
<th>Scene</th>
<th>Game story</th>
<th>Smog knowledge points</th>
<th>Textbook knowledge points</th>
<th>grade</th>
<th>Learning method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital</td>
<td><em>Bao</em> goes to the hospital to visit her desk-mates and promises to go out after he gets well.</td>
<td>Learn to view Air Quality Index Forecasts with AQI</td>
<td>Air pollution and protection</td>
<td>Six</td>
<td>Text description; Image show; Question Consolidation</td>
</tr>
<tr>
<td></td>
<td>While leaving the ward, <em>Bao</em> finds a poster on the wall of the hospitals corridor. She chooses to go closer.</td>
<td>Understand how air enters the body</td>
<td>Human organs for breathing</td>
<td>Four</td>
<td>Text description; Image show</td>
</tr>
<tr>
<td></td>
<td><em>Bao</em> finds an introduction about breathing.</td>
<td>Learn how inhalation and exhalation work</td>
<td>The lungs breathe through the diaphragm</td>
<td>Four- Expanding knowledge</td>
<td>Choose interaction; Text description; Image show</td>
</tr>
</tbody>
</table>

3.2.4 Design Interface

After summarising the knowledge and setting up the game script, we needed to design the image of the game interface. The player enters the main interface, clicks the button to start the game, log in as the main character of the game (*heroine AiBao*), and the game will enter the task scene interface.

The game will first explain elements like mood values, health values, smog building, AQI etc. Next, the player enters the park scene to perform the first task of the game. It uses a form in which the player triggers a story to lead out a dialogue, and is equipped with music, competitions and other game elements.

Figure 4 below is our game task scene interface and Figure 5 is our game dialogue interface.

![Figure 4. Game task scene interface](image-url)
3.3 Expected Outcome

- The game can strengthen the understanding of smog and related smog-protection knowledge and cultivate the awareness of self-protection on smoggy days among students in grades 4-6.
- Through a form of entertainment, students can be placed in the appropriate situations to learn in the game. When faced with a similar situation in real life, the student can reasonably apply the experience and knowledge gained from the game.
- The game can help students develop the habit of focusing on the theme of environmental pollution and pay more attention to self-protection and prevention of harm in real life.

4. TEST AND EVALUATION

After completing the prototype of the game, we evaluated the learning effect through a questionnaire and scale to find out whether the game has aroused students' interest in learning by using it. After that, we conducted an interview. Based on the participants’ suggestions, we will improve and optimise the game.

4.1 Theoretical Basis of the Test

This questionnaire is designed based on Flow theory and Game Flow model. Mihaly Csikszentmihalyi, a Hungarian American psychologist, introduced the concept of flow in the 1990s. Csikszentmihalyi (1993) believes that flow is a state of mind in which a person is fully engaged in an activity. Sweetser and Wyeth (2005) found a part of Flow related to Game experience, and put forward the Game Flow entertainment assessment model.

This model has eight highly distinct indicators: clear goals, appropriate challenges, concentration, player competence, game control, game feedback, game immersion and social interaction. The eight indicators have a one-to-one correspondence with the elements of Flow. The indicators selected in this test include whether the goal is clear, whether the challenge is appropriate, whether the attention is focused, the player's ability and the difficulty of the game control.
4.2 Experimental Procedure and Method

Our experimental procedure is shown in Figure 6 below, and questionnaire survey and interview were used in it.

![Diagram of experimental procedure]

**Figure 6. Experimental procedure**

1. **Questionnaire Survey**
   - We adopted the questionnaire and scale in design and experience research for Shih Chi card educational games based on flow theory (Zhang, 2016) to test game immersion. It is a seven-point Likert Scale and it includes five dimensions: ease of understanding, game difficulty, difficulty of understanding game rules, game interest and excitement towards subsequent content.

2. **Interview**
   - After the questionnaire was completed, we conducted an interview to gain insight regarding the game’s flaws and areas for improvement.

4.3 Evaluation and Result

Twelve questionnaires were collected and all collected questionnaires were valid. Table 2 shows the results:

<table>
<thead>
<tr>
<th>Question</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>The game background story is complete and easy to understand</td>
<td>6.50</td>
<td>0.50</td>
</tr>
<tr>
<td>The game is very difficult</td>
<td>3.08</td>
<td>1.98</td>
</tr>
<tr>
<td>The rules are easy to understand</td>
<td>6.42</td>
<td>1.11</td>
</tr>
<tr>
<td>This game is interesting</td>
<td>6.50</td>
<td>0.50</td>
</tr>
<tr>
<td>I am looking forward to future game content</td>
<td>6.42</td>
<td>0.49</td>
</tr>
</tbody>
</table>

As above results, the game background story is relatively complete, and the rules are easy to understand with interesting game content. As for the difficulty level of getting started
in the game, there was a wide range of results. Some players thought it was easy, but some thought it was difficult.

During the experiment, we obtained the precise amount of time spent by players to play through the game by behavior observation. Next, we gathered data about the amount of time the players felt they spent through the questionnaire. Figure 7 shows that while participants were playing the game, the amount of time they felt had passed less than or equal to the real amount of time spent, which conforms to Flow Theory.

![Figure 7. Time you felt and the time you spent while playing the game](image)

The questionnaire results demonstrated that the immersion and stickiness of the game were both high. The game has aroused players’ interest in learning.

Eight students were interviewed. Two of them thought that the gameplay was too text-heavy. One of them indicated that the knowledge required was a little difficult and he hoped that we could add more pictures. Another student suggested that we make our game 3D. Another suggested that we add a game-save capability to save player progress. A final student had no improvement advice.

4.4 Improvability

From the interview part, it can be seen that “the quantity of text is large” was a common reflection. The questionnaire part reflects that the difficulty setting of the game has some problems.

The most important point we should improve is to abridge text and add more appropriate animation to help with understanding. We can also add a function to archive the progress to make sure that player can continue the game when they log-in again.

5. CONCLUSION

Following GBL theory, mobile learning theory and Flow theory, we developed a smog-themed educational game application that combines math and science knowledge selected from higher-grade stages of primary school. We hope to enhance students’ interest and motivation in learning environmentally relevant knowledge by using this educational game.
By analysing the results of the questionnaire survey and the interview, we can conclude that players had a strong flow experience when playing the game, which indicates that the stickiness and interest of the game is relatively high, and it does improve the player's interest in learning. Zhang (2016) reached the same conclusion. In addition, Lei and Yang’s (2017) research on educational game literature at home and abroad shows that educational games can stimulate students' learning motivation, promote students' cognitive development and facilitate students to form a positive learning attitude, which also confirms our conclusion.

There are some limitations in this study. Firstly, the educational game itself can be improved, such as abridging text and adding more elucidating animation. Secondly, the quantity of participants in this study was small and consequently the reliability of the conclusions is general. In the future, we need to expand the test scale, which is conducive to better data statistical analysis and higher reliability of conclusions.

REFERENCE

ABSTRACT

Teachers’ self-efficacy in teaching integrated science, technology, engineering, mathematic (STEM) plays critical roles in promoting its implementation at classroom level. However, there has been little studies investigating the factors influencing teachers’ self-efficacy in adopting STEM education. In order to have a better understanding of the development status of STEM education in China and to explore the potential variables influencing STEM teaching self-efficacy, this study reviewed the relevant existing studies and investigated the effects of school support (i.e., competence support, autonomy support, collegial support), pedagogical knowledge, and sociological factors (i.e., gender and school location) through quantitative methods. The results showed that the influence of gender, school location, and school support on STEM teaching is significant. In addition, the school support and pedagogical knowledge in urban area is significantly higher than in rural areas. The results indicated that school administrators should provide more effort to improve teachers STEM teaching experience, and governments should take measures to narrow the regional gap. Implications and suggestions for further studies and the implementation of STEM education are provided.

Keywords: Primary teacher, teaching self-efficacy, school support, pedagogical knowledge, sociological factors

1. INTRODUCTION

With the rapid development of information and computer technology (ICT) and complex society, our students are required to equip themselves with 21st literacy skills to face the future challenge in profession (Saavedra & Opfer, 2012). Numerous reports and studies have stressed the important role of integrated science, technology, engineering, and mathematic mathematics (STEM) curriculum in fostering students’ problem-solving, critical thinking, and innovation (National Research Council, 2014; Sias, Nadelson, Juth, & Seifert, 2017). Although plenty of countries have promulgated corresponding policy and documents to encourage the development of STEM education, the implement of reformed education approach at the classroom level still faces lots of challenges and barriers (Breiner, Johnson, Harkness, & Koehler, 2012). It requires teachers equipped with the required skills and knowledge to enact it into teaching practice.

Qualified teachers have always been the main force of education reformation. However, due to the in-service teachers lacking relevant experience of STAM approach and support from social context, it is too difficult for teachers to enact the innovative education in their teaching practice (Bissaker, 2014). A substantial of studies have argued that teachers’ self-
efficacy is linked to teachers’ perception and behavior. Teachers with a strong sense of their ability to plan and arrange teaching activities tend to spend more effort in improving their teaching, overcome the challenge, and adopt innovative teaching method (Blonder & Rap, 2017). Therefore, exploring the factors influencing teachers’ self-efficacy can contribute to the implement of STEM education.

Based on the above analysis, this study aims to investigate the status of primary teachers’ STEM teaching self-efficacy in China. And further exploring the support from school administration, teachers’ own PK lever, and some sociological variables on their teaching self-efficacy. This study will contribute to the understanding of ways and strategies to facilitate teachers’ practice in innovative teaching and promote the implementation of STEM education.

2. LITERATURE REVIEW

2.1. STEM teaching self-efficacy

Teaching self-efficacy is derived from Bandura’s self-efficacy, which was defined as “people’s beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives” (Bandura, 1977, p. 71). One of the dominant models for teaching self-efficacy was developed by Tschannen-Moran, Hoy, and Hoy (1998), who defined teaching self-efficacy as “teachers’ belief in her or his ability to organise and execute the courses of action required successfully accomplish a specific teaching task in a particular context” (p. 22). The extent of teachers’ self-efficacy has been argued to correlate with the quality of their instruction and, in turn, with students’ educational outcomes, such as achievement, interest, and motivation (Holzberger, Philipp, & Kunter, 2013; Zee, de Jong, & Koomen, 2016). Self-efficacy is commonly understood as domain- and context-specific; teachers can have different levels of self-efficacy beliefs in different situation. Therefore, when exploring the potential factors influencing teaching self-efficacy, several aspects should be taken into consideration.

2.2. Factors influencing teacher self-efficacy

Considering the development of STEM education is top down, introduced and encouraged from country level, the attitude and measures from school administration plays critical roles in influencing teachers’ perception and performance in implementing STEM education. The prior studies have suggested that the sufficient training program, teaching resources, infrastructure environment, and collaborative community are essential contextual factors to teachers’ professional development and adoption of educational innovations (Thurlings, Evers, & Vermeulen, 2015). Therefore, this study assumed that school support has effects on teaching self-efficacy on STEM practice.

In addition, teachers’ pedagogical knowledge (PK) is critical to teachers’ confidence in teaching. PK defines knowledge about instructional practices, principles, and strategies to manage classrooms and organise the teaching of the subject matter (Shulman, 1987; Mishra & Koehler, 2006). Differing from traditional education, teaching STEM requires teachers to create real-world problems and context to engage students in inquiry and learning (EL-Deghaidy, Mansour, Alzaghibi, & Alhammad, 2017). Competence to adopt student-centred teaching approach to carry out teaching activities may have a positive effect on teachers’ belief of their teaching.

What’s more, prior studies have argued that teachers’ self-efficacy is influenced by some sociological factors. For example, male teachers are found to be more confident than female teachers when integrating technology into their classroom teaching (Teo, Fan, & Du, 2015). But the influence of gender does not always exist. The area where a school is located
is another important factor. The different levels of economic development determines the development level of education to some extent (Harjanto, Lie, Wihardini, Pryor, & Wilson, 2018). Therefore, this study intends to investigate the differences in urban and rural area in China and explore its effect on teaching self-efficacy.

In summary, this study adopts school support, PK level, gender, and school location as four variables to explore their influences on teacher’ teaching self-efficacy of STEM through quantitative method, while at the same time, showing a picture of the development status at school and teacher level in China’ STEM education.

3. METHOD

3.1. Participants

The participants for our study were 247 primary school teachers (M age = 32.71, SD = 6.894). There were 69 (27.9%) male and 178 (72.1%) female. Among these participants, 141 (57.1%) came from rural areas and 172 (42.9%) came from urban areas. The detailed participants information of this study is shown in Table 1.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Options</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>male</td>
<td>69</td>
<td>27.9%</td>
</tr>
<tr>
<td></td>
<td>female</td>
<td>178</td>
<td>72.1%</td>
</tr>
<tr>
<td>School Location</td>
<td>rural</td>
<td>141</td>
<td>57.1%</td>
</tr>
<tr>
<td></td>
<td>urban</td>
<td>172</td>
<td>42.9%</td>
</tr>
<tr>
<td>Age</td>
<td>20-30</td>
<td>99</td>
<td>60.3%</td>
</tr>
<tr>
<td></td>
<td>30-40</td>
<td>98</td>
<td>39.7%</td>
</tr>
<tr>
<td></td>
<td>Above 40</td>
<td>50</td>
<td>20.2%</td>
</tr>
<tr>
<td>Teaching years</td>
<td>Under 10</td>
<td>129</td>
<td>52.2%</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>69</td>
<td>27.9%</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>46</td>
<td>18.6%</td>
</tr>
<tr>
<td></td>
<td>Above 30</td>
<td>3</td>
<td>1.2%</td>
</tr>
<tr>
<td>Level of education</td>
<td>High school or below</td>
<td>15</td>
<td>6.1%</td>
</tr>
<tr>
<td></td>
<td>University or college</td>
<td>213</td>
<td>88.6%</td>
</tr>
<tr>
<td></td>
<td>Graduate school or above</td>
<td>19</td>
<td>7.7%</td>
</tr>
</tbody>
</table>

3.2. Instruments

The instrument was adapted from several sources. School support was measured using the instrument developed by Lam, Cheng, and Choy (2010). The original instrument included three constructs, namely competence support, autonomy support, and collegial support, with a total of 10 items.

The researchers translated all item into Chinese, and a university professor in the field of educational technology validated the Chinese translation. Pedagogical knowledge was measured using the instrument validated in Sang, Tondeur, Chai, and Dong (2016) with 7 items. STEM teaching self-efficacy was measured by the instrument developed by Lin and Williams (2016) with 5 items. We obtained the Chinese version questionnaire from the two studies. The final survey, comprised of 27 items, measured teachers’ perception of support they get and the extent to which their beliefs with pedagogical knowledge and teaching efficacy. Each item was rated as a five point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree).
3.3. Data collection and analysis

The data were collected using online survey. Teachers answered the survey anonymously. The responses were then collated in SPSS. The exploratory factor analysis demonstrated that pedagogical knowledge and teaching self-efficacy were unidimensional factors, while support included competence support, autonomy support, and collegial support. Factor loadings of all items were above 0.5. The respective Cronbach’s alphas were: competence support (α = 0.91), autonomy support (α = 0.84), collegial support (α = 0.94), pedagogical knowledge (α = 0.94), STEM teaching self-efficacy (α = 0.95). Further analyses including Pearson correlation, t test were also performed.

4. RESULTS

4.1. Descriptive statistics and correlations

The results shown in Error! Reference source not found. demonstrated that all the five factors correlated with each other. In addition, the average scores illustrated that competence support teachers acquired was the lowest (M = 2.83, SD = .91). Meanwhile, their autonomy support (M = 3.26, SD = .86), collegial support (M = 3.25, SD = .95), pedagogical knowledge (M = 3.63, SD = .67), and teaching self-efficacy (M = 3.24, SD = .80) were at medium levels.

Table 2. Descriptive statistics and correlations

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Competence support</td>
<td>-</td>
<td>.74***</td>
<td>-</td>
<td>.44***</td>
<td>.56***</td>
</tr>
<tr>
<td>Autonomy support</td>
<td>.55***</td>
<td>-</td>
<td>.57***</td>
<td>-</td>
<td>.61***</td>
</tr>
<tr>
<td>Collegial support</td>
<td>.75***</td>
<td>-</td>
<td>.59***</td>
<td>-</td>
<td>.59***</td>
</tr>
<tr>
<td>Pedagogical knowledge</td>
<td>.44***</td>
<td>.57***</td>
<td>.59***</td>
<td>.69***</td>
<td>-</td>
</tr>
<tr>
<td>STEM teaching self-efficacy</td>
<td>.56***</td>
<td>.61***</td>
<td>.59***</td>
<td>.69***</td>
<td>-</td>
</tr>
<tr>
<td>M</td>
<td>2.83</td>
<td>3.26</td>
<td>3.25</td>
<td>3.63</td>
<td>3.24</td>
</tr>
<tr>
<td>SD</td>
<td>.91</td>
<td>.86</td>
<td>.95</td>
<td>.67</td>
<td>.80</td>
</tr>
</tbody>
</table>

*Note.*** p < .001

4.2. Influences of gender and school location

The effects of gender are shown in Error! Reference source not found.. As we can see, independent samples t-tests revealed that the differences in school support (including competence, autonomy, and collegial) and pedagogical knowledge between male and female were not significant (p > .05). While there is a significant difference (t = 2.211, p < 0.5) between the two groups in STEM teaching self-efficacy.

Table 3. t test of teachers' sex

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>M</th>
<th>SD</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competence support</td>
<td>Male</td>
<td>2.89</td>
<td>.843</td>
<td>.674</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>2.81</td>
<td>.937</td>
<td></td>
</tr>
<tr>
<td>Autonomy support</td>
<td>Male</td>
<td>3.27</td>
<td>.817</td>
<td>.137</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>3.25</td>
<td>.879</td>
<td></td>
</tr>
<tr>
<td>Collegial support</td>
<td>Male</td>
<td>3.37</td>
<td>.896</td>
<td>1.202</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>3.21</td>
<td>.966</td>
<td></td>
</tr>
<tr>
<td>Pedagogical knowledge</td>
<td>Male</td>
<td>3.75</td>
<td>.644</td>
<td>1.885</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>3.58</td>
<td>.671</td>
<td></td>
</tr>
<tr>
<td>STEM teaching self-efficacy</td>
<td>Male</td>
<td>3.42</td>
<td>.742</td>
<td>2.211*</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>3.17</td>
<td>.808</td>
<td></td>
</tr>
</tbody>
</table>

*Note. * p < .05
The results in Error! Not a valid bookmark self-reference. shows that the differences between rural area and urban area teachers in competence support ($t = -4.583, p < 0.001$), autonomy support ($t = -6.026, p < 0.001$), collegial support ($t = -4.555, p < 0.001$), pedagogical knowledge ($t = -5.170, p < 0.001$), and STEM teaching self-efficacy ($t = -5.515, p < 0.001$) are all significant.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>M</th>
<th>SD</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competence support</td>
<td>Rural</td>
<td>2.61</td>
<td>.856</td>
<td>-4.583***</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>3.12</td>
<td>.902</td>
<td></td>
</tr>
<tr>
<td>Autonomy support</td>
<td>Rural</td>
<td>2.99</td>
<td>.818</td>
<td>-6.026***</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>3.61</td>
<td>.786</td>
<td></td>
</tr>
<tr>
<td>Collegial support</td>
<td>Rural</td>
<td>3.02</td>
<td>.942</td>
<td>-4.555***</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>3.56</td>
<td>.870</td>
<td></td>
</tr>
<tr>
<td>Pedagogical knowledge</td>
<td>Rural</td>
<td>3.44</td>
<td>.644</td>
<td>-5.170***</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>3.87</td>
<td>.622</td>
<td></td>
</tr>
<tr>
<td>STEM teaching self-efficacy</td>
<td>Rural</td>
<td>3.01</td>
<td>.788</td>
<td>-5.515***</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>3.54</td>
<td>.702</td>
<td></td>
</tr>
</tbody>
</table>

Note. *** $p < .001$

4.3. Influences of school support and pedagogical knowledge

In order to investigate the effects of school support and pedagogical knowledge on STEM teaching efficacy, this study divided the participants into different groups according to their scores on each dimension. Participants with scores higher than average were assigned to the high group, and participants with scores lower than average were assigned to the low group. The differences between these groups in STEM teaching self-efficacy are shown in Table 5. The results show that competence support ($t = 7.725, p < 0.001$), autonomy support ($t = 8.034, p < 0.001$), collegial support ($t = 7.967, p < 0.001$), and pedagogical knowledge ($t = 10.939, p < 0.001$) all significantly influence STEM teaching self-efficacy.

<table>
<thead>
<tr>
<th>Group</th>
<th>Competence support</th>
<th>Autonomy support</th>
<th>Collegial support</th>
<th>Pedagogical knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>M</td>
<td>3.58</td>
<td>2.87</td>
<td>3.58</td>
<td>2.86</td>
</tr>
<tr>
<td>SD</td>
<td>.623</td>
<td>.804</td>
<td>.624</td>
<td>.795</td>
</tr>
<tr>
<td>$t$</td>
<td>7.725***</td>
<td></td>
<td>8.034***</td>
<td></td>
</tr>
</tbody>
</table>

Note. *** $p < .001$

5. DISCUSSION

This study first takes an overview of Chinese primary teachers’ self-efficacy level, pedagogical knowledge level, and the support they get from schools and colleagues. The results indicated that teachers’ confidence and belief on their ability to enact innovative
STEM approach and accomplish successful learning goals is relative low in Chinese primary schools. We suggest that the Chinese government and school administrators should pay close attention to problems and take effective measures to improve teaching self-efficacy, which is critical to high quality of teaching. Prior studies have demonstrated that teachers’ self-efficacy could be improved through successful experience (Morris, Usher, & Chen, 2016). The significant effect of school support and pedagogical knowledge in this study indicates that school administrators could provide sufficient professional training opportunities to enhance teachers’ master of innovative teaching method and increasing teachers’ experience of STEM. Meanwhile, it’s important for school leaders to encourage teachers to become curriculum design peers and collaboratively work on design and organise STEM activity. In addition, the significant difference between male and female teachers still suggest to us that schools should pay more attention to female teachers’ self-efficacy.

The results from competence support, autonomy support, and collegial support, demonstrated that investment in different areas of China is unbalanced. Considering the important effects of school support found in this study, measures to narrow the regional gap is essential to a balanced development of reformed education. In addition, the difference between the two areas (rural versus urban) in pedagogical knowledge is also significant.

6. CONCLUSION

As we have already noted, developing STEM education has become a priority in many countries, including China. However, despite evidence of the positive impacts of teaching self-efficacy on teachers’ practice in teaching innovation, there exists a dearth in understanding the effective factors influencing teachers’ self-efficacy. This study addressed this question using quantitative method.

The results suggest the importance of school support and teachers’ own teaching skills on their STEM self-efficacy. In addition, the significant difference between urban and rural areas demonstrates the big gap in different areas in China. Further studies should try to explore effective ways to support STEM teachers to collaboratively design STEM curriculums. The government and school leaders should increase support for teachers’ professional development.

REFERENCE


INTEGRATING COMPUTATIONAL THINKING IN STEM EDUCATION THROUGH PROJECT-BASED LEARNING

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ABSTRACT

This study presents the design and implementation of a science, technology, engineering, and math (STEM) + C (computing) curriculum for upper elementary students (4th to 6th grade) in an after-school program for eight weeks. The STEM+C curriculum, which was guided by the project-based learning (PBL) approach, consists of two PBL projects and aims to integrate computational thinking (CT) in STEM education. Preliminary results with seventy-two students in after-school settings showed that the STEM+C curriculum significantly improved students’ attitude toward mathematics. However, there was no significant difference regarding students’ attitudes toward science, engineering, and technology before and after their eight-week participation. The discourse analysis of weekly video recordings of students while participating in two PBL projects revealed a range of complexity and variation of CT in students. Main implications of the study provide insights for how to integrate computational thinking in K-12 (kindergarten to high school) STEM education, how to design a STEM+C curriculum, and the design of learning tasks and learning activities to facilitate the development of CT competencies in students.

Keywords: Computational thinking, STEM+C curriculum, computing education, project-based learning (PBL), robotics, engineering design

GOALS AND OBJECTIVES

Computational thinking (CT) is a thought processes that involve critical thinking and problem solving skills (Wing, 2006). More and more educational researchers and practitioners have adopted the perspective of computational thinking as critical thinking skills that go beyond programming and coding.

While CT is a fundamental skill for all students (Wing, 2006), it is widely missing in K-12 (meaning kindergarten to high school) curricula (Lye & Koh, 2014; National Research Council [NRC], 2011). Research on the development of computational thinking in K-12 students has not received as much attention as that of mathematical thinking and scientific reasoning (Lye & Koh, 2014). Therefore, there is an immediate need to integrate CT into K-12 education.

Due to links between CT and the disciplines of science, technology, engineering, and mathematics (STEM), such as problem solving and scientific reasoning (Sengupta,
Kinnebrew, Biswas, & Clark, 2012), the development of CT in students is highly relevant to their STEM learning (National Science Board [NSB], 2010).

This paper describes the design and development of a project-based, STEM +C (STEM+ Computing) curriculum for 4th to 6th grade students. The paper reports the preliminary outcome of the implementation of the STEM+C curriculum on students’ attitude toward STEM and the development of CT in students.

THEORETICAL FRAMEWORK

The design and development of the STEM+C curriculum was guided by a project-based learning (PBL) approach. PBL is “a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process” centred around complex and authentic questions (Buck Institute of Education [BIE], 2017, para. 4).

In PBL, all learning activities and objectives are driven by an overall guiding question. Hands-on elements (e.g., research, solving problems, creating products) are embedded within project-based learning, offering opportunities for real world, problem solving. At the end of a PBL unit, students showcase their final product or creation often through a final competition.

THE STEM+C CURRICULUM

The STEM+C curriculum consisted of two project-based learning projects. One was Life on Mars and the other was Building Earthquake-Resistant Bridges. The Life on Mars’ overall driving question was: How can we detect life on Mars using a robot? The Bridge project’s overall driving question was: How can we build a bridge for the Boise River that is strong enough to resist earthquake forces? Both projects were designed to invigorate students to learn and integrate CT and STEM to solve the overall driving question over eight weeks.

The Life on Mars was designed to engage students to learn and apply CT and integrate science, engineering, and technology through robotics and programming. Recent research suggests the value of robotics in education lies in the hands-on opportunities that engage students in applying knowledge and skills they have learned from various disciplines (Eguchi, 2014; Scaradozzi, Sorbi, Pedale, Valzano & Vergine, 2015). Scientific knowledge and concepts (e.g., forms of lives, the planet of Mars) and robotics and programming concepts were introduced in the first four weeks.

Students assembled robots using Lego Mindstorms kits and programmed the robots with EV3 software featuring drag-and-drop programming interface. Starting in the 5th week, students assembled and programmed a robot to prepare for a final competition. In the final 8th week, students showcased their robots to detect whether there was life (a symbol) on a simulated Mars environment built by the researchers. The robot/team that found the symbol of life in the shortest time would win the competition.

The other STEM+C project, Building Earthquake-Resistant Bridges, was designed to engage students to learn and apply CT and integrate STEM through engineering design and bridge building. At the core of the engineering design process for K-12 students are: defining and identifying a problem; developing possible solutions; designing and testing prototypes; and making revisions (Chabalengula & Mumba, 2017). Research showed that the use of engineering design in science education has improved student learning in science (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Wendell & Lee, 2010). The recent K-12 STEM education reforms in the United States have promoted new connections between science and engineering education.
For example, the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) emphasise the integration of engineering design in science curriculum to enhance science learning and engineering design skills among students. In the Bridge project, scientific knowledge and engineering concepts (e.g., earthquakes, bridges) were introduced in the first four weeks. The engineering design concepts (e.g., developing possible solutions and building prototypes) were introduced in later weeks while students were designing and building bridges using K’Nex building kits.

Starting the 5th week, students designed and built an earthquake-resistant bridge and prepared for the final competition. In the final 8th week, students competed for the best bridge design. The bridge/team that passed the pre-determined earthquake testing criteria set up by the researchers and used the least amount of resources in building their bridge would win the competition. Each of the K’Nex pieces had a price tag associated with it, which the students had to keep track of the cost while building their bridges for the final competition.

**RESEARCH DESIGN**

The context of the study was in the after-school programs at four community centres serving four Title I schools (meaning students from low social and economic families) respectively. Each community centre was attached to one school. Seventy-two 4th to 6th grade students and twelve teachers were recruited to participate in the study in the spring and fall 2017.

The STEM+C curriculum was implemented with the recruited students and teachers in small groups of six students with one teacher per group, twice per week for a total of eight weeks. The implementation took place in late afternoons in the participating teachers’ classrooms following regular school time. The participating community centers recruited all the students.

In this study, we focused on how the STEM+C projects impacted students’ attitude toward STEM and how it helped develop CT in the students.

**Data Collection**

Multiple types of data were collected from students, including student attitudes toward STEM survey (Friday Institute for Educational Innovation, 2012), video recordings of students for eight weeks, and students’ work, notes and products.

The researchers also conducted a focus group of student interviews at the end of each implementation semester to understand student learning and triangulate the data.

**PRELIMINARY RESULTS**

The preliminary results reported in this study were based on the students’ attitude toward STEM survey and the analysis of the weekly video tapings of the students in spring and fall 2017 semesters. The survey outcome showed that the STEM+C curriculum had a significant impact on students’ attitude toward math (*p*= .019) (Table 1).

However, there was no significant difference regarding students’ attitude towards science, engineering and technology before and after the 8-week program.
Table 1: Student attitude towards STEM

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>T</th>
<th>Df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std. Deviation</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Std. Error Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95% Confidence Interval of the Difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Pre_M - Post_M: -1.5472, 4.6557, .6395, .6395, -2.8304, -2.419, 52, .019*
- Pre_S - Post_S: -.1509, 5.0284, .6907, .6907, -1.5369, 1.2350, 52, .828
- Pre_ET - Post_ET: 1.0566, 5.3795, .7389, .7389, .2662, 2.5394, 1.430, 52, .159

*statistically significant at .05 level.

Sfard’s (2008) discourse framework was adapted to analyse computational thinking revealed in students through coding the video tapings. Sfard’s framework emphasises learning as a lasting change in one’s scientific discourse. There are four characteristics of scientific discourse: **word use** (words and their use), **routines** (well-defined repetitive patterns and characteristics of the given discourse), **endorsed narrative** (spoken or written descriptions of objects) and **visual mediators** (visual structure to provide meaning to an object).

For **word use**, we examined student’s use of CT language, such as speed, distance, variable, scale, materials, constraints, and magnitude, to explore how knowledge is communicated and constructed through interactions. The CT language often overlaps with the STEM content terminology. For **routines**, we looked for how students approached solving a problem, such as using CT via abstraction and decompositions of a problem. For **endorsed narrative**, we looked for CT element related to (oral or written) communication and the consensus or agreement regarding the communication, which is different from actual actions causing physical changes. For **visual mediators**, we looked for CT related to data structures/analysis/representation and simulations and modeling, such as sketches or drawings of robots and bridges.

The researchers chose to analyse the video tapings of students’ work from week 1 (at the beginning of the project), week 4 (in the middle) and week 7 and 8 (at the end), which were anticipated to show different levels of CT because of the different learning objects (sub driving questions).

The discourse analysis indicated that students exhibited different types of computational thinking (Table 2). Table 2 presents some of the discourse analysis of the weekly video tapings showing the growth of CT in students as they proceeded in the STEM+C projects.

Table 2. The growth of CT in students revealed in weekly video taping

<table>
<thead>
<tr>
<th>Life on Mars</th>
<th>CT category</th>
<th>Week 1: Sub question: What does life consist of?</th>
<th>Week 4: Sub question: How to program a Lego robot to make turns using Gyro sensor?</th>
<th>Week 7 &amp; 8: Sub question: How can we program our robot for detecting water on the Mars simulation?</th>
</tr>
</thead>
</table>
The preliminary results also showed a range of complexity and variation in computational thinking during student scientific inquiry and problem solving, which may be due to the increasing complexity of the learning tasks students were involved in each week. For example, for the learning task of researching “what does life consist of?” in the Life on Mars project, the CT elements revealed in the students’ oral presentations/discussions mainly fell into the word use category. The N/As in Table 2 do not necessarily imply that a CT component did not occur in a specific category.
CONCLUSION

The results showed that the STEM+C PBL projects helped improve student’s attitude towards math. Although math is only one of our focuses in the curriculum, it turned out to be salient to students. Students had to use math frequently in both projects.

In the Life on Mars project, students needed to understand the degrees and rotation concepts while programming their robots for moving forwards and making turns as well as measuring distance. In the Bridge project, students needed to measure the dimensions of their bridges as well as calculate the cost for their bridge design. However, there was no significant difference between student attitudes toward science, engineering and technology before and after their participation for this particular group of students.

This may indicate that the integration of CT needs a good foundation to build on in terms of which subject content area we choose to infuse CT. For this particular group of participants, math takes the second place behind language and literary in terms of the amount of time they spend on in every day classrooms, while they spend little to no time on science, engineering and technology. In future CT integration, more effort and research needs to be placed on science, technology and engineering subject content areas.

The STEM+C projects also helped develop CT concepts and competencies in the students. However, it seemed that the kind of CT which students developed and revealed may very much depend on the specific tasks and learning objectives students were involved in based on the variations of CT revealed during different weeks and different learning objectives. Therefore, we need to provide the specific learning activities/tasks to students if we want to develop special types of computational thinking, such as CT concepts or CT practices as described by Grover and Pea (2018) in students.

This study has significant implications for the design of computational rich learning environments and teaching STEM subjects via the integration of CT.

ACKNOWLEDGMENT

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We also wish to thank Dr. Yu-hui Ching and Dr. Sasha Wang for their effort in the curriculum design and data collection of this study.

REFERENCES


ABSTRACT

This paper reports a case study that investigated how parents with low formal education in a rural Community in West Africa support their children’s mathematics learning. Data were collected from six select parents and their 9-10 year old children. The data corpus consisted of semi-structured individual face-to-face interviews and home visit observations. Through an Afrocentric framework, thematic analysis of this data revealed that 1) rural parents with low formal education seek support from others with mathematics knowledge and skills within the community, and 2) they create an environment supportive of mathematics assignments and learning activities. These findings are significant and offer insights into how parents with low formal education from a non-western cultural context are deeply involved in their children’s mathematics learning. Furthermore, the findings bring into question the often-held view that meaningful parental involvement is only limited to middle class families.

Keywords: Parents, children, mathematics learning, culture, Afrocentricity

INTRODUCTION

The general school and community participation in children's education has a long-standing history dated back to early works of Yeager's (1946) and lately Epstein et al. (2002) on school community relationships. In the context of Ghana, Nyarko's (2011) work on school achievement and parental involvement is an example of such a study conducted in this area.

Specific to children's mathematics learning, there is research into parents or family involvement strategies across the globe, mostly in the western context. While some researchers advocate for more structured programmes to endanger parental involvement in children's mathematics learning, others have recommended direct parents assistant as a way to get families involved. For instance, "Math Club" project, a parental involvement intervention programme which was introduced to two public high schools at different times in Australia (Muir, 2011) and more recently, Knapp, Landers, Liang and Jefferson's (2016) "Mathematics Knowledge for Parental Involvement" (MKPI) in South Eastern United States are few examples out of many interventions. These programmes are aimed at equipping parents with adequate mathematics content knowledge needed to assist their children (mostly K-8 graders) to excel in school mathematics. The successes of these programmes were largely hinged on parents' ability to master the school mathematics content of their children as they participate in special tutoring programmes designed for parents (Knapp et al., 2016; Muir, 2011).
Other forms of involvement include the provision of homework support. For instance, O'Sullivan, Chen, and Fish’s (2014) study employed survey to investigate various approaches parents employ in assisting their children's mathematics homework in some urban communities in the United States. O'Sullivan et al. (2014) concluded that parents mostly provide direct assistance or engage their children in school-sanctioned mathematics activities at home as well as helping them to overcome homework difficulties.

Some studies within western Canada with middle-class parents have also pointed to how children (age 6-8) learn mathematics concepts such as addition and subtraction during board games activities with their parents (Phillips, Norris & Anderson, 2008). Although there is research into local games and their relationships to mathematics within the African context (Powell & Temple, 2002), there is little to no literature on how parents might engage their children in such games to enhance their mathematics learning.

While studies across the western contexts (e.g. Knapp et al., 2016; Muir, 2011, Phillips et al., 2008) provide insights into some parental involvement practices in children's mathematics learning, they also tend to suggest that parents need appreciable levels of formal education and perhaps some mathematics pedagogical strategies to be meaningfully involved in their children's mathematics learning. This assertion delineates other forms of support or involvement practices that parents may give their children at home and more specifically parents with low or no formal education who may not be able to decipher the school mathematics content of their children. Thus, it remains under-researched how non-middle class, non-western parents with low or no formal education are engaged in their children's mathematics learning. Premised on the above, this study investigated how parents with low or no formal education are deeply involved in their children's mathematics learning in the context of rural West Africa.

OBJECTIVES

In this paper, we present research findings and discussion on how parents in a rural community in West Africa are engaged in their children's mathematics learning drawing on values of the community. Specifically, we report a study that employed case study approach to investigate how six parents with low formal education in a rural community support their 9-10-year-old children's mathematics learning to highlight the need for teachers and other educators to appreciate the supportive role rural parents with low or no formal education play in their children’s mathematics learning.

THEORITICAL PERSPECTIVES

This study draws on the Afrocentric framework (Asante, 1990) which encompasses a host of culturally relevant theories including the sociocultural theory of learning in highlighting the role of knowledgeable adults in mediating children's learning (Rogoff, 1991; Vygotsky, 1978). The use of Afrocentric framework enabled us to discuss how parents or families are engaged in children's mathematics learning from an African perspective and within rural West Africa context. Asante (1990) described "Afrocentricity" a framework that employs worldviews, myths, motifs, symbols embedded in African culture to reinforce the centrality of the African as a valid frame of reference to inquire, understand and analyse problems related to Africans (Asante, 1990; 1999; Asante & Karenga, 2005; Dei, & Kempf, 2013).
The most central tenet of Afrocentricity is the non-separation of man, nature and the invisible (supernatural). The existence of these creates a unified and complete entity (Dixon, 1977). By implication, humans must internalise and personalise the phenomenal world and thrive in harmony with their surroundings. The non-separation of man and his environment or surroundings and interconnectedness of all things in an Afrocentric sense translates to the social lives of African people where the individual becomes a non-existent being without the community or the collective society. Phrased differently, ‘who you are or become’ is the result of your relationship with the community. Therefore, the value orientation of oneness or communalism redefines the concept of family as going beyond the nuclear to include extended members (uncle, Aunt, nephews, niece, nannies, grandparents, elders in the community, etc.).

This is important especially in research with African families where the meaning of "family" may be very encompassing. The conceptualisation of the family in Afrocentric worldview shapes the expected roles and responsibilities of families and community and how they are involved in children's mathematics learning. Children's mathematics learning and how knowledge is acquired in an Afrocentric sense is inseparable from the cultural activities, values, and the way children are socialised into the world (Dei, 1996). In other words, relationships and interactions which families and the larger community engage children, within the socio-cultural settings, tends to frame how children are supported in their mathematics learning and education in general at home and within the community (Dei & Kempf, 2013).

METHODOLOGY AND DATA ANALYSIS

To better understand how rural parents' involvement in children's mathematics learning, a case study design (Yin, 2003) that employs interviews and home visits observation was employed. Data was collected from six rural parents and their children. The case study design enabled us to work closely with a small number of participants that allowed us to delve deeper into the ways parents with a low level of education support their children's mathematics learning. Parents' and children's interview data sets, as well as observational field notes from home visits, were examined for common patterns and possible nuances.

In each data set, transcribed interviews were compared and grouped into descriptive categories (i.e. common themes). The field notes from home observations were also categorised under relevant themes as further evidence. The consistency of phrases, statements and words in the data corpus that provided clues in answering the research questions were noted and categorised. That said, for a theme to be named it was not necessary for all six families (either parent or child) to express common statements, phrases or words. Rather, if at least one parent shared a practice, which in turn surfaced a number of times in the remaining data sources, a theme was formed. Initial phrases describing the possible themes were constructed and rephrased several times until clear meanings of the commonalities and patterns within the participants' responses became stabilised or consistent across the data set. Using this constant-comparative method, these themes were used to further cull the remaining data.

RESULTS

The results of the study are presented in themes that emerged through systematic analysis of the data corpus. The analysis indicated that 1) rural parents with low formal education seek support from others with mathematics knowledge and skills within the
community 2) they create an environment supportive of mathematics assignments and learning activities

**Children’s mathematics learning as a communal responsibility**

This theme was most prominent in the parents’ data sets. The supervisory role of parents in enhancing their children's mathematics learning run through all six family's (parent-child) data sets. In some cases, parents did not mention this but it was evident in their children's data corpus. All parents except one, John (P4), mostly rely on the academic strengths of either siblings or other members of the community/neighbours to support their children.

Parents (Alison and Susan) seem to rely on additional support for their children's mathematics learning at home. For instance, while Alison (P1) requests such support from neighbours, Susan (P2) does similar through her child's sibling. In both cases, parents indicated that they ensure their children get the needed supervision and assistance. In the case when parents find it difficult in offering support due to their low level of formal education, they rely on neighbours and other community members for the needed help. For example, Paulina (P3), Mercy P5 and Vic P6 find it difficult offering any form of support for homework in mathematics because they all dropped out of school at the lower primary level and had very limited knowledge of any form of formal school mathematics. In such instance, parents (e.g. Paulina (P3) and Vic (P6) ) seek the needed help for their children from either the children's siblings or other members of the community.

As Paulina (P3) and Vic (P6) noted respectively:

*I want my child to do well in mathematics. Sometimes I let the elder sister help him with his homework and make sure he learns after school hours and also phone my friend to help her with difficult math problems.\*

*I always ask her about mathematics homework and makes sure she does it before she goes out to play or watch television. I tell her to contact her cousin who is in primary 6 for assistance. There is also one man behind this house whom I sometimes call to help her with school homework.*

Although Mercy (P5) did not indicate her supervisory role at home in her son's mathematics homework, in a separate conversation, her son Zimba (L5) expressed how his mother ensures he gets the needed mathematics support from people in the neighbourhood. Sandy (L6) expressed similar. Thus, parents in the study either explicitly expressed by themselves or through their children in the data corpus, they ensure their children get the needed mathematics support at home either through their children's siblings, neighbours or community members.

**Creating an environment supportive of mathematics and learning activities**

Parent’s participants in the study provide enabling environment for children to engage in mathematics learning activities at home and among these include playing local games such as ludo and oware with their children or better still, provide the opportunities for their children to engage in such games with friends or neighbours. Although this was expressed differently by the participants, there was a convergence of opinion that the parents (e.g., Alison (P1), Susan (P2), John (P4), and Mercy (P5)) place value and importance on playing local games as a way of enhancing their children's mathematical learning. For instance, Alison (P1) and Susan (P2) shared that they play ludo and oware with their daughters for fun as well as helping them build their "counting skills". Likewise, John (P4) shared that he was very much aware of "educative games like oware and Dame (Ghanaian version of chess)", he does not have such games at home but encourages his son to play the games with friends.
Evidence from the data suggests that some parents in this study engage their children in local mathematics games at home while others provide the resources or chance for their children to play such games. However, some parents were unaware of the implicit or explicit mathematics connection per se or at least did not articulate the mathematical nature of the games as others did.

**DISCUSSIONS AND CONCLUSIONS**

The results of this study indicate that parents with no formal education engage children's siblings, neighbours, and the larger community to support their children's mathematics learning at home. As it is grounded in the cultural practices of the community where this study was conducted, every adult sees a younger child as a son or a daughter irrespective of family relationship and appears responsible for the child's learning. This resonates with the Afrocentric worldview (Asante, 1990) of family and communal living where capable adults in the community have a stake in the general learning and socialisation of the child in both school and out-of-school experiences with an emphasis on mathematical competency. In this sense, "neighbourness" or community plays a tremendous role in the child's mathematics learning in contrast to the most western community where individualism appears to be the case. Thus, the findings of this study differ from previous studies in the western context (e.g. De Jong, Westerhof, & Creemers, 2000; O'Sullivan et al., 2014) where the focus of family or parental involvement is mostly on the role of the nuclear parents in their children's mathematics learning and less or no attention is paid to the role other community members or neighbours may play. Therefore, this study challenges educators and researchers to think more broadly of contributions of other knowledgeable others within the community especially in a context like West Africa where communal living is upheld (Dei, 1996), valued and definition of "family" goes beyond the nuclear family.

Finally, parents with no or low formal education create a supportive mathematics learning environment where children are freely engaged in local games (oware and ludu) to enhance their children's mathematics learning. The local games contrast Lego, building blocks, or IPads used by children in contemporary western societies. Although the games parents described in this study differ and are culturally specific to the community, the result of the study corresponds to Phillips' et al. (2008) study with middle-class parents in western Canada who pointed to engage their children in board games in support of their mathematics learning. Despite such differences, parents in this study believed playing such cultural specific games with their children or creating opportunities for them to play such games would enhance their children's mathematics learning.

Therefore, it can generally be theorised that the cultural setting of a society or community plays a significant role in the kind of interactions and mathematics learning environment parents regardless of their educational level, may provide for their children at home - may it be games or daily household activities. In other words, the mathematics interactions, activities or environment parents provide for their children may differ from culture to culture. Even if peculiar task or activity differs, it worth acknowledging that parents whether low education or middle-class support math through child-friendly activity. This study, therefore, adds to the building evidence that socio-cultural practices of families do influence the specific kind of activities and the supportive mathematics learning environment parents may create to foster children's mathematics learning. That's said, despite the potential of such local games in promoting mathematical thinking and reasoning (Powell & Temple, 2001), it worth to acknowledge that the explicit mathematical interactions that emerge when parents engage their children in such local games remain unknown. However,
for parents with low formal education to recognize such socio-cultural games as contexts within which they support their children’s mathematics is a significant contribution, in itself.

REFERENCES


DEVELOPMENT AND PRACTICES OF THE UBIQUITOUS GREENHOUSE FOR TECHNOLOGY EDUCATION IN JUNIOR HIGH SCHOOL

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ABSTRACT

In junior high school technology education in Japan, students need to learn four learning areas evenly and experientially. It is difficult to learn in limited class hours and teaching materials that can comprehensively study these fields are required. In this study, we have developed the Ubiquitous Greenhouse as a project based learning content of technology education in junior high school. We used Raspberry Pi as the control system. Raspberry Pi acquires weather data of remote areas in real time, and reproduced the Ubiquitous Greenhouse by controlling multiple home appliances based on the data. We conducted lectures using the Ubiquitous Greenhouse for junior high school third graders. The students were divided into groups and worked on the production of the Ubiquitous Greenhouse. After the production, the students carried out the plant breeding experiment using the Ubiquitous Greenhouse. As the results, the students confirmed that the Ubiquitous Greenhouse functions correctly. According to the questionnaire after the practice, most students were ambitiously working on the production of the Ubiquitous Greenhouse and were comprehensively learn the learning contents of technology education.

Keywords: Greenhouse, Raspberry Pi, Technology Education

INTRODUCTION

The objective of technology education in junior high school in Japan is to enable students to acquire fundamental and basic knowledge and skills related to materials and their processing, energy conversion, nurturing living things and information processing through practical and hands-on learning activities such as production (monodukuri), while also fostering the ability and attitude to evaluate and utilise technology properly. It is also important to cultivate problem solving skills against challenges in order that students respond autonomously to the changing society (Ministry of Education, culture, sport, science and technology-Japan [MEXT], 2008). This is a project based learning as a problem-solving type learning method. In order to be a learning content for project based learning, it is necessary for the learning content to include a learning process, where students find and solve challenges themselves.

We devised the Ubiquitous Greenhouse as a project based learning content that students can comprehensively when learning the four fields. The Ubiquitous Greenhouse is a greenhouse that can reproduce a weather of a remote place in real time by controlling greenhouse using remote meteorological data.

Some studies have showed measurement control of remote places such as Field server and LiveE! Project (Ezaki, 2006). Other studies have showed cultivation support system by
controlling weather inside a greenhouse (eLab experience, n.d.). However little study has been done to reproduce the weather of a remote place in real time by controlling greenhouse. The Ubiquitous Greenhouse can be a practical and experimental learning content for project based learning by using as a teaching material from a development stage.

In the present study, we have developed the Ubiquitous Greenhouse as a project based learning content, and have conducted a plant breeding experiments using it.

THE UBIQUITOUS GREENHOUSE

The Ubiquitous Greenhouse can reproduce temperature and humidity of a remote place in real time. We used Raspberry Pi as the control system. Solid-state relays were used to control four home appliances. Table 1 shows the development environment of the Ubiquitous Greenhouse. Fig.1 shows the Ubiquitous Greenhouse.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer</td>
<td>Raspberry Pi Model B+</td>
</tr>
<tr>
<td>OS</td>
<td>Raspbian Jessie</td>
</tr>
<tr>
<td>Development language</td>
<td>Python</td>
</tr>
</tbody>
</table>

![Fig1. The Ubiquitous Greenhouse](image)

**Solid-state Relay**

A solid-state relay is an electric switching device that switches on or off. The input terminals of the solid-state relays are connected to I/O pins of the Raspberry Pi by soldering. Since it is not desirable that the output terminals of a solid-state relay be connected to a power cord of a home appliance, it is connected to an extension cord by processing it. Extension cords were inserted with fuse. The Solid-state relays connected to the refrigerator and the heater were attached to a radiator because they got very hot.

**Measurement of Temperature and Humidity of the Ubiquitous Greenhouse**

We used DHT11 to measure the temperature and humidity inside the Ubiquitous Greenhouse. DHT11 is a digital temperature and humidity sensor (DHT11 Temperature and Humidity Sensor V2 SKU: DFR0067, n.d.). It used a capacitive humidity sensor and a thermistor to measure the surrounding air, and spits a digital signal out on the data pin. Raspberry Pi acquire the data of temperature and humidity by connecting the three cords of
DHT11. We have created an instrument shelter for DHT11 because DHT11 cannot measure properly without an instrument shelter. Figure 2 shows the instrument shelter we created.

![Fig 2. The instrument shelter](image)

**Acquisition of Temperature and Humidity data of Remote Places**

Raspberry Pi acquire the data from AmeDAS on the Web published by the Japan Meteorological Agency. We used the Beautiful Soup module which is a Python library for Web scraping (Mitchell, 2018). Raspberry Pi extracts the latest temperature and humidity data based on the current time from the acquired data.

**Control Home Appliances**

Raspberry Pi compares the temperature and humidity data of the remote place with the temperature and humidity data in the Ubiquitous Greenhouse. It then controls the home appliances based on the comparison result so that the weather in the Ubiquitous Greenhouse is closer to the weather in a remote place. For example, if the temperature in the remote place is higher than the temperature in the Ubiquitous Greenhouse, Raspberry Pi turns on the heater.

**THE PLANT GROWING EXPERIMENTS**

We conducted plant growing experiments using the Ubiquitous Greenhouse. We selected radish and white radish sprouts as plants to use for the experiments because they growth easily and quickly. We selected Naha City as a remote place to reproduce in the Ubiquitous Greenhouse. We cultivated plants in the outside air of Higashihiroshima City to compare with the Ubiquitous Greenhouse.

On December 12, 2016, we prepared two similar plastic containers and planted four seeds of radish in each container. We placed one container in the Ubiquitous Greenhouse and the other in the outside air of Higashihiroshiima City. We put about 50ml of water once a day in each container. After 6 days, the radish in the Ubiquitous Greenhouse germinated, but the one grown in the outside air of Higashihiroshima City did not change.

After 10 days, the stem of the radish in the Ubiquitous Greenhouse grew to a length of 7.2cm, but the length of the radish grown in the outside air of Higashihiroshima City did not change. Figure 3 shows a comparison of the lengths of the radish stems and the temperature between Higashihiroshima City and the Ubiquitous Greenhouse during the radish growing experiment. According Figure 3, the temperature in Higashi Hiroshima City is generally considerably lower than the temperature in the Ubiquitous Greenhouse. The temperature in the Ubiquitous Greenhouse is suitable for the growth of these plants. However, the temperature of Higashihiroshima City is not suitable for the growth of radish.
Fig 3. Comparison the lengths of the radishes stem and the temperature between Higashihiroshima City and the Ubiquitous Greenhouse

Figure 4 shows a temperature and humidity comparison while raising radish between the Ubiquitous Greenhouse and Naha City. Despite some errors, the Ubiquitous Greenhouse reproduced the temperature and humidity of Naha City in general.

Fig 4. Comparison of temperature and humidity during the radish grow experiment

On January 10, 2017, we prepared the same two plastic containers, put wet paper towel and sowed 20 seeds of white radish sprouts in each container. We placed one container in the Ubiquitous Greenhouse and the other in the outside air of Higashihiroshima City. We put about 50ml of water in each container each day.

After 2 days, the radish in the Ubiquitous Greenhouse gminated, but the radish grown in outside air of Higashihiroshima City did not change. After 12 days, the stem of the radish in the Ubiquitous Greenhouse grew to a length of 11.5cm, but the stem of the radish grown in the outside air of Higashihiroshima City did not change.

Figure 5 shows comparison the lengths of the radishes stems and the temperature between Higashihiroshima City and the Ubiquitous Greenhouse during the white radish sprouts growth experiment. According Figure 5, the temperature in Higashi Hiroshima City is generally considerably lower than the temperature in the Ubiquitous Greenhouse. The temperature in the Ubiquitous Greenhouse is suitable for white radish sprouts growth. However, the temperature of Higashihiroshima City is not suitable for white radish growth.
Fig 5. Comparison the lengths of the white radish sprouts stem and the temperature between Higashihiroshima City and the Ubiquitous Greenhouse

Figure 6 shows two graphs comparing the temperature and humidity while raising white radish sprouts between the Ubiquitous Greenhouse and Naha City. The Ubiquitous Greenhouse reproduced the temperature and humidity of Naha City in general as well as the radish grow experiment.

Fig 6. Comparison of temperature and humidity during white radish sprouts experiment

CLASS PRACTICE

We planned classes based on the developed greenhouse, and then conducted classes for junior high school third graders from April 10, 2017 to January 22, 2018.

We decided to deal with the following contents in the production of the Ubiquitous Greenhouse so that students can comprehensively study the four fields. For materials and their processing, students made instrument shelters. In making instrumental shelters, the students designed them by taking into consideration their purpose. Students assembled cardboard cut to design specification. In energy conversion, students assembled Solid-state Relay kits with a soldering iron. After that, they checked the assembled Solid-state Relays with an ammeter. In nurturing living things, students select distant places to reproduce considering difference in weather condition here. They also planned cultivation of plants in plant breeding experiments. In information processing, students created control programs for home appliances to reproduce temperature and humidity in remote areas.

In order to investigate whether the Ubiquitous Greenhouse functioned properly as a teaching material, we conducted a questionnaire to the students. The questions are as follows:

- Have you understood the Ubiquitous Greenhouse system?
- Have you found the work carried out in producing the Ubiquitous Greenhouse interesting?
- Have you felt that producing the Ubiquitous Greenhouse was difficult?
• Through the plant growing experiment, have you realised that home appliances are controlled by program programs?
• Through the plant growing experiment, have you realised that the Ubiquitous Greenhouse reproduced the meteorology of the remote place?
• Have you realised the difference in plant growth as the result of the plant growing experiment?
• Have you been interested in the production using technologies in various fields?

The questionnaire result are shown in Figure 7.

![Fig 7. The questionnaire result](image)

According to the questionnaire result, most students selected 4 or 5. Most students comprehensively learned learning contents of technology education in junior high school. It is shown that the Ubiquitous Greenhouse can be effectively utilised as a teaching material. However, while some students felt it was easy to produce the Ubiquitous Greenhouse, others felt it was difficult.

CONCLUSION

In this paper, we have described details of the Ubiquitous Greenhouse for technology education in junior high school. After that, we have described practice lessons using the Ubiquitous Greenhouse for junior high school third graders. Junior high school students can comprehensively learn the learning contents of technology education by using the Ubiquitous Greenhouse from the development stage as a teaching material. In addition, the Ubiquitous Greenhouse can be project-based learning content by challenging unresolved study. As a future study, it is necessary to improve the Ubiquitous Greenhouse easier to handle as a teaching material.

REFERENCES


THE EFFECTS OF A VISUAL GAME PROGRAMMING ENVIRONMENT ON PROGRAMMING EDUCATION FOR ELEMENTARY SCHOOL STUDENTS

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ABSTRACT

Computer programming education is widespread around the world. It has a direct connection with computational thinking which has received considerable attention recently. Computational thinking is viewed as a critical and necessary skill in the 21st century that everyone should learn. In addition, six years ago, Wing had argued for adding this new competency to every child’s analytical ability as a vital ingredient of science, technology, engineering, and mathematics (STEM) learning. The study was aimed to analyse the effects and possibilities of the Swift Playground (a visual programming tool) through activities in primary education, especially focused on programming attitude, concepts and the usability and edutainment of Swift Playgrounds. This study investigated the development of 20 students’ computational perspectives in 4th to 6th grade through visual programming course with swift playground. It adopted one-group pre- and post-test design and collected data through questionnaire. The results showed that the visual programming environment could effectively enhance students’ programming attitude and concepts. Moreover, there was little difference in the attitude toward programming between genders in elementary school.

Keywords: Computational Thinking, Elementary Education, Visual Programming environment

INTRODUCTION

In recent years, computer programming education has attached much attention in elementary education (Wilson, Hainey, & Connolly, 2013). In terms of the development of computer programming skills, Lye and Koh (2014) believed that programming education is an effective way to cultivate students’ computational thinking. Researchers argued that Computational Thinking (CT) is a fundamental skill for not only computer scientists but almost everyone (Zhong, Wang, Chen, & Li, 2016).

Wing (2006) believed that CT was the process of applying problem-solving, system design, and human behaviour understanding of basic concepts about computer science. It included a series of thinking activities that cover computer science and can be as important to students as reading, writing, and arithmetic. Researchers claimed that CT was an essential skill as reading, writing, and other basic language arts skills, pointing out that “programming is a language for expressing ideas (National Research Council, 2010). In addition, some other researchers have also stated that the CT has five elements of abstraction, generalisation, decomposition, algorithm, and debugging (Angeli et al., 2016).

Although there was still no precise definition of computational thinking, the three-dimension framework of CT constructed by Brennan and Resnick (2012) including computational concepts, computational practices, and computational perspectives have been
recognised by many researchers. The computational concepts refer to the concepts used by the designer when programming; the computational practices refer to the practice that the designer develops in programming, and the computational perspectives refer to the designer’s formation which relates to the world around them and their ideas. This theoretical framework helps researchers conduct practical research in computational thinking. Through these experiences, they are expected to establish a computational identity and achieve digital empowerment (Kong, 2016).

**Cultivation of CT through visual programming**

Programming for K-12 can be traced back to the 1960s when Logo programming was first introduced as a potential framework for teaching mathematics (Feurzeig, Papert, & Lawler, 2011). Papert (1980) claimed that the Logo programming experience could develop powerful intellectual thinking skills among children. To better adapt to this digital age, Kong (2016) proposes a seven-principle framework to design the curriculum in K-12 to promote CT through programming. After Logo, the use of programming to teach computational thinking skills in K-12 was not extensively reported.

However, in recent years, the availability of visual programming languages such as Scratch and Alice have been modeled after aspects of Logo (Utting, Cooper, Kölling, Maloney, & Resnick, 2010). Chang (2014) looked for the most frequent use of features from the Scratch and Alice program languages and examined how they were employed in the implementation of a computer programming course. For these visual programming tools, students' interest is stimulated through the use of block-style drag and drop. Swift is a programming language developed by Apple Inc. Swift Playgrounds was introduced by Apple in 2016, and it is a coding environment that allows a user to interact with Swift code without requiring the user to create a project. Imagine launching Xcode, selecting a playground file as the option and getting started coding.

“Swift Playgrounds is a revolutionary app for iPad that makes learning Swift interactive and fun” (Swift Playgrounds, n.d.). It requires no coding knowledge, so it is perfect for students just starting out. Learning to code with Swift Playgrounds is incredibly engaging, playing your way through the basics in “Fundamentals of Swift” using real code to guide a character through a 3D world and then move on to more advanced concepts. In Swift playgrounds, what you see is what you code. You can create code on the left side of your screen and instantly see the results on the right side. With just a tap, drag, or type text and numbers, you can then interact with what you’ve created. There are also lots of robots and drones you can control with Swift Playgrounds, which can design many interesting activities. People can import and export directly between Swift Playgrounds and X code and try out any ideas with the tool to develop iOS and Mac apps. Therefore, this study uses Swift Playground, the visual programming tool on iPad, to conduct programming education for elementary school students.

Fig 1. Screenshot of Swift Playgrounds
**Effects of the visual programming environment**

People highlight the benefits of the integration of Computer Science into K-12 education. As for the effects of the visual programming environment, researchers have different viewpoints. Programming is not only a fundamental skill of computational science and a vital tool for supporting the cognitive tasks involved in computational thinking but a demonstration of computational competencies as well (Grover & Pea, 2013).

The study conducted a six-week course on "Promoting Fundamentals of Computational Thinking" in secondary schools, focusing on the basics of computing and related capabilities in computing thinking in the form of Scratch-based task teaching. Sáez-López, Román-González, & Vázquez-Cano (2016) assess the use of a Visual Programming Language using Scratch in classroom practice, analysing the outcomes and attitudes of 107 primary school students from 5th to 6th grade in five different schools in Spain. Atmatzidou, Demetriadis, and Nika (2017) employed an appropriate CT model to explore students’ CT skills development in two different age groups and across gender and found that students eventually reach the same level of CT skills development independent of their gender; however, girls appear in many situations to need more training time to reach the same skill level compared to boys. The study of Shim, Kwon, & Lee (2017) based on diverse experimental results, proposes an environment where elementary students can easily learn and practice computer programming. It concentrated on the tool’s usability and entertainment aspects, and students’ attitudes toward programming and their understanding of programming concepts improved.

According to all the above studies, it is interesting to explore the different visual programming tools to create a visual environment for the better effects. The research presented here aims to propose a practical educational programming environment for young students with the useful programming tool. Besides, it will assess the effects of the visual programming environment including the attitude toward programming, the difference it has between gender, the tool’s usability and entertainment, and the understanding of programming concepts.

**AIMS**

The primary objective of the study is to analyse the effects and possibilities of enhancing CT with a visual programming environment through projects and activities in primary education. The specific objectives are:

1. To assess the attitudes of primary school students regarding programming by using a Visual Programming Language with Swift Playgrounds.
2. To analyse the attitudes of primary school students’ difference between gender with Swift Playgrounds.
3. To check the usability and edutainment of Swift Playgrounds.
4. To assess acquisition of basic computer programming concepts in primary education with Swift Playgrounds.

**METHODS**

This study adopted a single group, pre- and post-test design and carried out for four rounds. Five participants took part in at each round, and data was collected before and after class.
Participants
The participants of this study were 20 elementary school students (10 boys and 10 girls) from Grade 4 to Grade 6. Seven participants were from Grade 4, nine participants were from Grade 5, and four of them were from Grade 6.

Instructional design
The instructional design was adopted from the teaching guide provided by Apple (Swift Playgrounds, n.d.) with a problem-based learning approach. It consisted of four themes including “commands & For Loops” “Conditional Code & Logical Operators”, “While Loops & Algorithms”, and activities with “Sphero & MeeBot”. The participants took one theme course in each round.

Instruments
The questionnaire developed by Shim et al. (2017), which has two parts, was used to evaluate participants’ attitude towards programming and the programming tool’s usability and edutainment. As shown in Table 1 & 2, there are 14 items about the attitudes towards programming and 9 items about the programming tools. All choices were measured using the Likert 5-scale, which included five options from “completely disagree”, “disagree”, “agree”, “more agree”, to “completely agree”, with the score of 1-5 respectively. The reliability coefficients of value, interest, and confidence are 0.849, 0.822, 0.93, and the KMO value was 0.926. Besides, it also adopted the questionnaire about computational concept. There are 9 items that need to be filled in the blanks, and the reliability coefficient is 0.876, the KMO value is 0.892.

Table 1. Questionnaire about programming attitude

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Questionnaire</th>
</tr>
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<tbody>
<tr>
<td>Value</td>
<td>I think that I can resolve practical problems through programming.</td>
</tr>
<tr>
<td></td>
<td>I think that I can live a successful life if I understand programming.</td>
</tr>
<tr>
<td></td>
<td>I think that programming is important for constructing something new in the future.</td>
</tr>
<tr>
<td></td>
<td>I think that programming will have a critical role in my life.</td>
</tr>
<tr>
<td></td>
<td>I think that today’s experiential learning is as important as learning math and science.</td>
</tr>
<tr>
<td>Interest</td>
<td>I want to ask questions of, or learn from, a person who is proficient at programming whenever I see him or her.</td>
</tr>
<tr>
<td></td>
<td>I want to befriend someone who is proficient at programming.</td>
</tr>
<tr>
<td></td>
<td>I enjoy using the concepts learned from programming activities.</td>
</tr>
<tr>
<td></td>
<td>I want to continue learning programming.</td>
</tr>
<tr>
<td>Confidence</td>
<td>I am confident of understanding contents related to programming.</td>
</tr>
<tr>
<td></td>
<td>I am confident that I can be proficient at learning programming.</td>
</tr>
<tr>
<td></td>
<td>I am confident that I can solve problems and tasks using programming.</td>
</tr>
<tr>
<td></td>
<td>I am confident that I can be proficient at doing something using programming.</td>
</tr>
<tr>
<td></td>
<td>I am confident that I can simplify a problem, or make it less difficult, using programming.</td>
</tr>
</tbody>
</table>
Table 2. Questionnaire about programming tools

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability</td>
<td>I think it’s easy to use this programming tool.</td>
</tr>
<tr>
<td></td>
<td>In this programming environment, it is easy to check and complete tasks.</td>
</tr>
<tr>
<td></td>
<td>I can easily manipulate and control this environment and tools.</td>
</tr>
<tr>
<td></td>
<td>It is very simple for me to explain how to use this programming tool.</td>
</tr>
<tr>
<td></td>
<td>I think the instructions of this programming environment are easy to remember.</td>
</tr>
<tr>
<td>Edutainment</td>
<td>It is fun for me to eat gems in the most effective way.</td>
</tr>
<tr>
<td></td>
<td>This game environment is very attractive to me.</td>
</tr>
<tr>
<td></td>
<td>I want to continue using this tool.</td>
</tr>
<tr>
<td></td>
<td>I want to play this game with classmates who have not played this tool.</td>
</tr>
</tbody>
</table>

RESULTS

Attitude toward programming

Results of independent-samples t-test of programming attitude indicated that the score of posttest was significantly higher than score of the pretest from the aspect of programming value (t (20) =5.036, p=0.001), programming interest (t (20) =8.141, p=0.002) and programming confidence (t (20) =6.307, p=0.009) (see Table 3).

Table 3. Participants’ programming attitude

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>20</td>
<td>3.240</td>
<td>0.820</td>
<td>5.036</td>
<td>0.001***</td>
</tr>
<tr>
<td>Posttest</td>
<td>20</td>
<td>4.550</td>
<td>0.713</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>20</td>
<td>3.138</td>
<td>0.821</td>
<td>8.141</td>
<td>0.002***</td>
</tr>
<tr>
<td>Posttest</td>
<td>20</td>
<td>4.900</td>
<td>0.300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confidence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>20</td>
<td>3.270</td>
<td>0.712</td>
<td>6.307</td>
<td>0.009***</td>
</tr>
<tr>
<td>Posttest</td>
<td>20</td>
<td>4.710</td>
<td>0.637</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: * p < 0.05; ** p < 0.01; *** < 0.001.

Gender difference in programming attitude

An independent sample t-test was conducted to analyse whether there was a gender difference in students' programming attitude. The analysis results as shown in Table 4 are that the score of posttest was no significantly higher than score of the pretest from the aspect of programming value (t (20) =0.093, p=0.738), programming interest (t (20) =0.292, p=0.198) and programming confidence (t (20) =0.281, p=0.798).

This result is different from the study of Sáez-López et al. (2016). They conducted computer teaching for students in different primary school grades and found that the development of students’ computational thinking is significant with regards to gender and grade.
Table 4. Programming attitude in gender

<table>
<thead>
<tr>
<th>Gender</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>10</td>
<td>3.267</td>
<td>0.993</td>
<td>.093</td>
<td>.738</td>
</tr>
<tr>
<td>Male</td>
<td>10</td>
<td>3.229</td>
<td>0.776</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>10</td>
<td>3.208</td>
<td>0.600</td>
<td>.292</td>
<td>.198</td>
</tr>
<tr>
<td>Male</td>
<td>10</td>
<td>3.108</td>
<td>0.918</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confidence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>10</td>
<td>3.200</td>
<td>0.619</td>
<td>.281</td>
<td>.798</td>
</tr>
<tr>
<td>Male</td>
<td>10</td>
<td>3.300</td>
<td>0.767</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < 0.05; ** p < 0.01; *** p < 0.001

Usability and edutainment of Swift Playgrounds

Participants’ perspectives on the usability and edutainment aspects of Swift Playgrounds are illustrated in Table 5. The result shows that the usability and edutainment elements scored higher than 3.5, indicating that Swift Playgrounds is suitable for elementary-level students, who can usefully participate in programming activities and can achieve educational efficiency.

Table 5. Usability and edutainment of Swift Playgrounds

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability</td>
<td>8.00</td>
<td>25.00</td>
<td>3.51</td>
<td>4.67</td>
</tr>
<tr>
<td>Edutainment</td>
<td>10.00</td>
<td>20.00</td>
<td>3.96</td>
<td>3.49</td>
</tr>
</tbody>
</table>

Understanding of programming concepts

Table 6 reports the understanding of programming concepts prior to and after the course, with \( p=0.001 \). Statistically, the understanding of programming concepts increased significantly, in which students solved problems using repeat, condition and parameter concepts.

Table 6. Understanding of programming concepts

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>20</td>
<td>0.4</td>
<td>0.17</td>
<td>3.90</td>
<td>0.001***</td>
</tr>
<tr>
<td>Posttest</td>
<td>20</td>
<td>0.5</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: * p < 0.05; ** p < 0.01; *** < 0.001.

DISCUSSION AND CONCLUSION

This current study investigated the cultivation of computational thinking through the visual programming tool (Swift Playgrounds). It was shown that the use of Swift Playgrounds significantly improved participants’ attitude towards programming and enhanced computational concepts about programming. In terms of the results about usability and edutainment of Swift Playgrounds shows that it is very useful and educational for elementary students.
As for the attitude towards programming, the results showed a significant increase in the three dimensions include value, interest, and confidence. Besides, the study showed that there is no significant difference in programming attitude between genders. The reason for this may be that Swift Playgrounds is different from previous programming tools, and can stimulate all students’ interest in learning programming greatly. Throughout the specific problem situations, it not only can improve their confidence in programming but also make programming no longer boring.

Moreover, different problem-solving strategies could be found during the observation. For example, in the "turn left" task, some participants used body gesture to help them to find the right direction, and some participants drew sketches before completing the task. As for this phenomenon, it is worthwhile for us to explore the relationship between cognitive styles, problem solve skills and computational thinking skills. And it can also compare the different effects of Swift Playgrounds with other visual programming tools.

REFERENCES


ABSTRACT

With the development of STEM education, how to evaluate learners’ improvement effectively has become a focus in recent years. A systematic review was conducted to provide an overview of assessment design of integrated STEM education in K-12 schools. The eligible SSCI journal articles through Web of Science™ Core Collection from 2007 to 2017 were located with two independent reviewers and synthesised. The results showed that the researches on assessment design in STEM were multiple rather than single. There were three data-collection methods such as self-reported measures, classroom observation, and artefact-based methods. Aspects of assessment were divided into four dimensions: students’ content knowledge, students’ skills, students’ emotion and attitudes, and the impact of the teacher. The study should be of interest to educators who are developing or implementing measures of STEM education assessment. We hope that the study could provide a reference for education researchers practitioners to carry out assessment design of integrated STEM education from learners’ perspective.

Keywords: Integrated STEM Education, Aspects of Assessment, K-12 Schools, Systematic Review

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education had received increasing attention over the past decade with calls both for greater emphasis on these fields and for improvements in the quality of curricula and instruction (National Research Council, 2014). With the widespread of STEM education, as an important aspect of STEM education, assessment had gradually been valued by relevant researchers.

What is integrated STEM education

Nadelson and Seifert (2017) defined integrated STEM as the seamless amalgamation of content and concepts from multiple STEM disciplines. The integration took place in ways that knowledge and process of the specific STEM disciplines are considered simultaneously. And it also took place in the context of a problem, project, or task. Problems that required an integrated STEM approach were typically ill-structured, with multiple potential solutions, and required the application of knowledge and practices from multiple STEM disciplines. In schools, integrated STEM was typically associated with project or problem-based learning (e.g., inquiry or design challenges), where the outcomes could vary widely and the
knowledge needed to be distributed across STEM disciplines. In contrast, segregated STEM involved an application of knowledge and practice exclusive to a single discipline, and in schools, the problems and activities associated with this end of the spectrum tended to be structured with single known answers. Besides, Mustafa, Ismail, Tasir, and Said (2016) emphasised the engineering process and considered that integrated STEM education could be defined as incorporating the theory and practices of science and mathematics education into technology and engineering education. In this study, integrated STEM education was defined as “an effort to explore teaching and learning between any two or more of the STEM subjects”.

**Integrated STEM education assessment**

The evaluation of integrated STEM education had raised researchers’ concerns in recent years. It was challenging work to design assessments that were effective for both discipline-specific and integrated learning. Historically, assessments had focused on concepts in a single discipline, with little attention to disciplinary practices or applications of knowledge. With the development of STEM education, it was found that the researches on assessment design in STEM were multiple rather than single. Different studies evaluated the knowledge, skills, and attitudes of learners based on different teaching content of STEM education. For example, Lou, Chou, Shih, and Chung (2017) used quasi-experiment design to explore the effects of integrating project-based learning into STEM activities and analysed the creativity of middle school students in carrying out activities. Two main tools were used to collect data in the research, namely "interview outline" and "Creativity Tendency Scale". Students’ problem-solving ability, cooperation ability, and ability to use technology in the course of activities were assessed. Kotkas, Holbrook, and Rannikmäe (2017) developed a program assessment tool to investigate the influence on students’ choices on STEM-related careers based on learning context. The Creative Teaching Semantic Scale (CPSS) developed by Besemer and Treffinger (1981) was used to evaluate the students’ creativity and academic performance. The results showed that students using digital tools had significantly better performance and creativity than students not using digital tools.

Through the online platform and the student group discussion, a series of tasks were designed using STEM knowledge to complete the production of the theme project “Audio Loudspeaker”, and the student’s works were the main reference for evaluation (Lou, Liu, Shih, & Tseng, 2011). Beckett et al. (2016) used a mixed evaluation method to evaluate students' participation in STEM activities. The Source is an alternative reality game (ARG) developed by Gilliam et al; the researchers evaluated students’ knowledge, skills, and professional interest in STEM by collating individual interview records of 144 participants and their classroom performance (Gilliam et al., 2017). Guzey, Moore, Harwell, and Moreno (2016) investigated students' mastery of STEM knowledge in the life sciences curriculum and their changes in STEM concepts and attitudes with a pre-test post-test research design.

There were two perspectives to take when considering measures of content and practices covered in a class. The first perspective focused on what teachers were doing in the classroom, whereas the second emphasised students’ experiences. Hamilton, Stecher, and Yuan (2017) described the rationale for examining new approaches to measuring students’ exposure to standards-aligned content and practices, reviewed what is known about currently available measures, and explored innovative approaches that might be adopted to create new measures. They considered both perspectives in this report, reviewed existing measures of instructional practice that focused primarily on teachers and explored additional measurement approaches that could provide evidence regarding what students were experiencing. However, very few studies had done a systematic review of the assessment of integrated STEM education from the learners’ perspective. The purpose of this study was to explore the
current situation of integrated STEM education assessment design from the learner’ perspective, summarised existing aspects of assessment, collect and analyse studies on published year, regions, data collection methods in the past ten years, to provide a reference for integrated STEM education assessment design for relevant educational researchers.

METHODS

The search and data extraction strategies used in the current study was adopted from Hwang & Tsai’s (2011) work.

Data resource

The procedure for locating and selecting studies was conducted using the following phases:

Firstly, two researchers searched the SSCI journal articles through the Web of Science™ Core Collection from 2007 to 2017, selected for all countries or regions, but selected for English. “STEM” was used as the keyword. The screened studies were selected based on research in science, technology, engineering, and mathematics, or the entire STEM education in a study. As a result, 1515 articles were yielded.

Secondly, the abstracts and full-texts were reviewed and rated. Two independent raters reviewed each abstract. A number of further criteria were specified to select appropriate studies for inclusion in the review. To be included in the review, papers had to (a) be related to teaching and learning of STEM education assessment, (b) involve students in K-12 schools, (c) be empirical studies (two of these studies were unavailable through the researchers’ institutional library subscription). In cases where the decision to retain or discard a study was not immediately obvious, two researchers reviewed the full-text article independently and then came together to make a final decision. Next, branching searches were performed using the reference lists of retrieved studies (there was one article included in this phase).

Forty studies that met the selection criteria were finally identified as relevant to the current study.

Coding framework

A range of different techniques had been used to measure instruction, including methods that rely on teacher self-reports, such as surveys, vignette-based measures, and instructional logs; methods that involve direct classroom observations; and methods based on analysing artefacts derived from the classroom, such as protocols to evaluate curriculum materials or student work (Hamilton et al., 2017). Through literature review, students’ content knowledge, skills, use of technology, interests in STEM-related college majors and careers, students’ perceptions and attitudes to STEM, impact of the teacher, engagement, self-efficacy, motivation were concluded as aspects of assessment.

The coding demission for current research was composed of two main sections:

1. Research identification: author, journal, published year, country or region, and students’ grade level (Kindergarten, Primary, Middle, Senior High school).
2. Assessment Design:
   - Aspects of assessment: students’ content knowledge, students’ skills (critical thinking, problem solving, creativity/innovation, computational thinking, collaboration, communication, computing/technology), students’ emotion and attitude (interests in STEM-related college majors and careers,
perceptions and attitudes to STEM, engagement, self-efficacy, motivation), impact of teacher;
• Data-collection method: self-reported measures, direct classroom observation, and artefact-based methods;
• Types of evaluation: formative assessment, summative assessment.

Inter-rater reliability
To assess inter-rater reliability with respect to the quality coding of the papers, a sub-sample of 10 of the 40 papers (25%) was coded independently by two raters. The inter-rater reliability (r) for the total scores was .98, showing good agreement between the two coders concerning the quality of the papers.

RESULTS

Descriptive analysis

Publication year
Figure 1 presented the distribution of 40 articles during the past ten years. The dispersal STEM assessment studies published in SSCI journal articles fluctuated from 2011–2017, with the maximum number of reviewed articles being twelve in 2017. The distribution of articles showed a more positive trend. Though there were eight articles published in 2014, only four articles pertaining to assessment of STEM education were retrieved for 2015. The highest number of articles reviewed was in 2017, contributed to the overall distribution of the reviewed articles.

![Figure 1. The Distribution of Reviewed Articles from 2007 to 2017](image)

Grade level distribution of the research studies
According to statistics most studies were conducted in the USA, with Taiwan coming in second, while few studies were completed in other countries and regions. Most participants involved in the included studies came from senior high schools, as shown in Figure 2. STEM education provides rich learning environments for students as well as increase the number of students who consider careers in STEM-related fields. Senior high school might be a crucial period for the students.
Figure 2. The Proportion of Grade Level

Table 1 Aspects of assessment in terms of the data collection methods, types of evaluation and the number of occurrences in articles

<table>
<thead>
<tr>
<th>Aspects of assessment</th>
<th>Number of Papers</th>
<th>Data-Collection Method</th>
<th>Types of Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Self-Reported Measures</td>
<td>Classroom Observation</td>
</tr>
<tr>
<td>Students’ content knowledge</td>
<td>16</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Problem solving</td>
<td>11</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Creativity/innovation</td>
<td>7</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Computational thinking</td>
<td>3</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Collaboration</td>
<td>10</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>2</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Computing/Technology</td>
<td>8</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Students’ emotion and attitude</td>
<td>16</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Interests in STEM-related college majors and careers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perceptions and attitudes to STEM</td>
<td>18</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Engagement</td>
<td>4</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>5</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Motivation</td>
<td>3</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Impact of the Teacher</td>
<td>2</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

Note: ✓=present.

Aspects of assessment

Based on the literatures, the authors sorted out the aspects of assessment appearing in the literatures in terms of the data-collection methods, types of assessments, and the number of occurrences in different articles, as shown in Table 1. From the literatures, aspects of assessment were summarised to four dimensions: students’ content knowledge, students’ skills, students’ emotions and attitudes, and impact of the teacher. Data-collection methods included self-reported measures, classroom observation, and artefact-based methods. The types of assessments included diagnostic assessments, formative assessments, and summative
assessments. When assessing the aspects, which data-collection methods were used and whether to use formative assessment or summative assessment.

Science played an important role in integrated STEM education. Most studies focused on the aspect of assessing scientific knowledge content. Engineering was usually used to design and practices, Data analysis and measurement was generally done by mathematics (Guzey et al., 2016). Students’ skill included critical thinking, problem solving, creativity/innovation, computational thinking, collaboration, communication, and computing/technology. Interests in STEM-related college majors and careers, perceptions and attitudes to STEM, engagement, self-efficacy, motivation were composed of students’ emotions and attitudes.

A key aim of the current review was to explore aspects of assessment which had been concluded from studies. Through the review, we found that when assessing knowledge, attitudes, and concept-related content, self-reported data collection methods were most frequently used. Other methods included comparing pre- and post-tests to analyse students' STEM-related knowledge, combining process assessment with the summative assessment regarding types of assessment, and using classroom observation methods for data collection, which is a process assessment when assessing student skills, engagement, motivation and so on.

**Types of assessment**

As shown in Table 1, at the K-12 education stage, researchers and teachers used a comprehensive evaluation system to provide students with different display opportunities and evaluated students’ knowledge reserves and classroom performances in various ways. The comprehensive evaluation system included three major assessment categories: diagnostic assessments, formative assessments, and summative assessments. In practical teaching, students' performance could not be judged by only one way. They needed to be evaluated by formative assessment combined with summative assessment so that the level of students and the teaching results of teachers could be determined more clearly. As the learning subjects, students participate in the construction of the evaluation system which could enhance the mutual exchange between educators and educates and is conducive to establish the evaluation system.

**CONCLUSION**

Through the analysis of STEM assessment related literatures, it is found that researches on related practice in the world had grown rapidly in the last decade. The assessment design had begun to become systematic. The assessment design of integrated STEM education assessment had gradually received attention and reflected the multiple assessment design orientation. The design of STEM educational activities was comprehensive, and the corresponding assessment should also be carried out in many ways and affirm the outstanding performances of students. During the evaluation, teachers should evaluate the student's ability levels in each dimension according to the student's completion in different aspects.

How to improve students' interdisciplinary learning ability and how to carry out STEM-related teaching activities more effectively should be explored in the future.
REFERENCES


AN EXPLORATION OF STEM ACTIVITY OF CONSTRUCTING DIGESTIVE SYSTEM MODEL IN PBL ENVIRONMENT

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ABSTRACT

Science, Technology, Engineering, and Mathematics (STEM) Education is beneficial to cultivate explorative and innovative spirits of students. PBL can cultivate students' ability to solve problems in the real world with cooperation. This study mainly aims to design a STEM activity integrated with PBL, and to explore the effects of the activity. The study involved 30 students from grade 4 to grade 6 in Beijing, which were divided into 6 groups. Students collected knowledge related to the situation of dyspepsia with groups, constructed a digestive system to explain digestion and absorption of food and designed a customized nutritional recipe. Data were collected from the pre- and post-surveys to analyse the students' cooperative ability and problem solving abilities in the activity. The activity involved knowledge of science, technology, engineering, mathematics, and aimed to improve students’ ability to solve problems in the real world. Three conclusions were drawn. First, the activity improved students’ understanding of core concepts in the digestive system. Second, the STEM activity integrated with PBL developed students’ cooperative and problem solving abilities. Third, the activity strengthened students’ ability to form crosscutting concepts and engineering thinking.

Keywords: STEM Education, PBL, Informal learning, Cooperative ability, Problem solving ability

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) Education is a cross-discipline study of students. PBL encourages students to imitate scientists’ process of exploration to solve the problem, and to share each other's point of view. Therefore, PBL cultivates students' ability to solve real world problems in cooperation. Nowadays, STEM education has been discussed as a critical issue inside and outside of schools. Its interdisciplinary and contextual features can be integrated with PBL. STEM education integrated with PBL is different from traditional learning, in that it tries to let students become active learners who actively acquire crosscutting knowledge to resolve problems that appear in the project, not be passive learners who always receive second hand knowledge (Thomas, 2000). STEM Education integrated with PBL refers to hand-on activities of students in activity participation, project design and problem solving. In the area of science education, STEM education integrated with PBL will help students study actively and improve the depth of creative thinking. STEM Education integrated with PBL encourages students to explore something they are interested in and, finally, to solve problems innovatively. Students can display the design of projects actively and creatively, create new ideas and collaborate with partners to solve problems. In that, two research purposes were specified:

1. to evaluate students’ performance in subject core concepts.
2. to analyse students’ variation of cooperative and problem solving abilities in the pre- and post-surveys.

LITERATURE REVIEW

STEM Education
STEM education integrates the contents of science, technology, engineering, and mathematics. In 1986, the National Science Foundation (NSF) released the “Undergraduate Science, Mathematics, and Engineering Education”, which reported the importance of the integration of science, mathematics, engineering, and emphasised the leader status of engineering education in the next generation of the World in Science. This was seen as the beginning of STEM education. In 2011 and 2013, the United States announced the “A Framework for K-12 Science Education” and the “Next Generation Science Standards” (NGSS), which integrated practices, crosscutting concepts and core ideas.

STEM Education integrated with PBL
STEM education integrates interdisciplinary knowledge to cultivate students’ innovative, creative thinking and operational ability (Pan, Jiang, & Chen, 2016). The integration innovation is based on the feature of STEM Education, and the purpose to solve problems in the real world.

PBL is driven by the project, integrates different subject issues when students solve complex problems through project practice and collaborative learning. PBL often requires students to cultivate integrated thinking. The final project will let scattered knowledge into integrated crosscutting knowledge. In response to solve a real complex problem, students can explore the best way to solve the problem. And learners will perform better in skill development, general ability and knowledge compilation, compared to those who do not use PBL (Tseng, Chang, Lou, & Chen, 2013).

STEM education integrates science, technology, engineering with mathematics. It has interdisciplinary, contextual, practical, collaborative and empirical features, which is suitable for integrating STEM education integrated with PBL (Yu & Hu, 2015). To sum up, STEM Education integrated with PBL is a suitable for interdisciplinary learning. STEM Education integrated with PBL is an interdisciplinary practice of students to cultivate problem solving and cooperative ability.

METHODS

To evaluate the effectiveness of the proposed approach, an activity was conducted on the “Constructing Digestive System Model” of a Science and Technology Museum in China. The goal of our activity is divided into three parts. First, to understand the core concept of digestive system. Students can tell the position and function of the digestive organs in the human body and make a healthy recipe to explain the digestive process of food; Second, to achieve cooperative learning goals. Students should realise the importance of collaboration in a group; Third, to develop problem solving ability. Students can explore different ways to solve problems.

The evaluation of the study used process evaluation and summative evaluation. Students’ performance, group worksheets and students' presentations were observed to evaluate the understanding core concepts of students. 5C Scales were used to evaluate collaboration and complex problem-solving abilities of students (Lai & Hwang, 2014).
Participants
The study took place in China Science and Technology Museum. 30 primary school students from grade 4 to 6 (10-12 year olds) participated in the experiments. Students were divided into 6 groups. The length of the activity was 90 minutes.

Experimental design
Since President Obama took office in 2009, he has consistently emphasised great importance to the cultivation of STEM talents and expressed the hope that students can acquire and deepen their critical thinking through STEM learning to excel in innovation skills and creativity (National Science Teachers Association [NSTA], 2009). This shows the importance of the cultivation of students’ critical thinking in the education of STEM education.

This study used the Creative Problem Solving model proposed by Treffinger, Isaksen, and Dorval (1994). It consists of three components: Understanding the problem, Generating ideas and Planning for action. At first, Understanding Problem consists of three stages: Mess Finding (MF), Data Finding (DF) and Problem Finding (PF). Then, Generating Ideas is associated with Idea Finding (IF). Finally, Planning for Action consists Solution Finding (SF) and Acceptance Finding (AF), as shown in Figure 1.

![Figure 1. Compositions of the Creative Problem Solving model](image)

This study adopts a quasi-experimental method and selects 30 students from grade 4 to grade 6. This activity aims to help students scientifically diagnose the illness and design a customised nutritional recipe by setting up a situation about dyspepsia.

In the stage of Understanding Problem, students need to analyse the ill organs by the performance and the pain area to learn core concepts about the digestive system. In this specialised situation, the first problem to solve is to diagnose which digestive organ has a problem. So students should learn interdisciplinary knowledge of the project in Figure 2, and form a general framework to solve the problem, and finally construct a model of the digestive system. The second problem is to make a personalised nutritional recipe.

![Figure 2. Students worksheet](image)  ![Figure 3. Materials and tools in the activity](image)
In the stage of Generating Ideas, students use materials in Figure 3 to visualise the digestive system and create a model (see Figure 4). During the process, they could clearly tell the digestion and absorption of food in different organs and make a scientific diagnosis of the indigestion situation. In the process of making a nutritional recipe, students could use scientific knowledge they learned to solve specific problem.

**Figure 4. Constructing the digestive system model**

In the stage of Planning for Action, students need to constantly improve and adjust their plans during the designing process of constructing the digestive system model. For example, in the process of measuring a six-meter-long rope as a large intestine, students may explore different methods to measure the length in Figure 5.

**Figure 5. Different methods to measure the length of the rope**

When making nutritional recipes, students can use different fruits and vegetables as long as they reach the requirements of easy digestion for indigestive patients. Finally, students represent the digestion and absorption of food and their personalised nutritional recipe (see Figure 6).

**Figure 6. Presentations of the digestive system model**
The entire activity is based on STEM Education integrated with PBL. The involved STEM element in the activity is reflected in Table 1. The design of the entire activity is generated from daily life. Under the guidance of the teacher, students search for information in groups. Finally, students can solve a series of health problems related to the digestive system and enhance the ability to solve problems in the real world.

### Table 1. The involved STEM elements in the activity

<table>
<thead>
<tr>
<th>Science (S)</th>
<th>Technology (T)</th>
<th>Engineering (E)</th>
<th>Mathematics (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The concept of digestive system</td>
<td>Selection of materials</td>
<td>Process of designing digestive system model</td>
<td>Calculation of the length of organ</td>
</tr>
<tr>
<td>The process of digestion and absorption</td>
<td>Use of tools to construct models</td>
<td>Process of designing nutritional recipe</td>
<td>Calculation of the volume of organ</td>
</tr>
<tr>
<td>The concept of nutrients</td>
<td>Processing, testing, adjustment and correction</td>
<td>Problem resolution</td>
<td>Unit conversion</td>
</tr>
</tbody>
</table>

### RESEARCH RESULTS

**Data Analysis**

After the activity, the teacher scored the answers in the worksheets of students to evaluate their understanding of the core concepts of the digestive system (see Table 2). Before and after the activity, students were suggested to do the pre-test (Cronbach's Alpha =0.869) and post-test (Cronbach's Alpha =0.906) of tendency scales. The scores were used as the basis for analysing change in cooperation tendency, creativity tendency and problem solving tendency. And we took t-tests on the data. In conclusion, after their participation in STEM project, students' cooperation tendency and problem solving ability have improved. The results were reported in Table 3.

### Table 2. The scores of students' understanding of core concepts

<table>
<thead>
<tr>
<th>Item</th>
<th>Number</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>understanding in subject core concepts</td>
<td>30</td>
<td>75.30</td>
<td>6.571</td>
</tr>
</tbody>
</table>

### Table 3. The Pre-test and Post-test of Scales.

<table>
<thead>
<tr>
<th>Item</th>
<th>Number</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>cooperation tendency Pretest</td>
<td>30</td>
<td>2.77</td>
<td>1.14</td>
<td>1.27*</td>
</tr>
<tr>
<td>Posttest</td>
<td>30</td>
<td>3.12</td>
<td>.48</td>
<td></td>
</tr>
<tr>
<td>creativity tendency Pretest</td>
<td>30</td>
<td>2.33</td>
<td>1.06</td>
<td>.046</td>
</tr>
<tr>
<td>Posttest</td>
<td>30</td>
<td>2.33</td>
<td>1.32</td>
<td></td>
</tr>
<tr>
<td>problem solving tendency Pretest</td>
<td>30</td>
<td>2.86</td>
<td>.93</td>
<td>1.92*</td>
</tr>
<tr>
<td>Posttest</td>
<td>30</td>
<td>3.04</td>
<td>.71</td>
<td></td>
</tr>
</tbody>
</table>

$p^*<.5$
Analysis of understanding of subject core concepts
Through data analysis, the subject knowledge score of the students was high (>60). Putting core concepts in specific project can not only enhance students’ interest in learning, but also improve students’ understanding and application of crosscutting knowledge. Students can apply interdisciplinary knowledge to solving the problem in the real world.

Analysis of cooperation tendency
Through the t-test, the difference between pre-test and post-test reached the level of significance (t=1.27, p<.5). Students' cooperation tendency has improved significantly before and after the course. In the activity, students carried out the project in groups; they expressed their own ideas, and discussed the better ways to solve the problem. In the whole process, every member took efforts to complete the project. Team members continuously evaluated and improved the team's digestive system model to develop scientific inquiry and practical ability.

Analysis of creativity tendency
Through the t-test, the difference between the pre-test and post-test didn’t reach the level of significance (t=.046). Students used crosscutting knowledge to model digestive system and integrate scattered knowledge into connected knowledge. When they designed customised nutritional recipe, their creativity tendency may be limited in some level which is hard to change at their age. Furthermore, a 90 minute activity can’t make the creativity tendency generate significance change immediately.

Analysis of problem solving tendency
Through the t-test, the difference between the pre-test and the post-test reached the level of significance (t=1.92, p<.5). Students’ ability to solve problems before and after the course have been significantly improved. By designing problems based on real situations, we encouraged students to use crosscutting knowledge to solve the real problem. In the activity, students can design the process to cultivate innovative and creative thinking. Through the process, students can evaluate and improve the project to form engineering thinking and hand-on practice ability.

CONCLUSIONS
STEM Education integrated with PBL aims to improve the deficiency of traditional teaching. STEM Education offers students a chance to accumulate experience in hands-on practice, and it enables them to integrate and apply related knowledge of science, technology, engineering and mathematics in the situation of “learning by doing and achieving enlightenment from mistakes”.

The study discovered that students’ subject core concepts, cooperation and problem solving ability are improved through the STEM activity integrated with PBL. Therefore, it is necessary to promote and apply this type of teaching to primary and secondary schools to help students improve STEM skills. Students can apply the STEM knowledge into practice with collaboration. And students will improve the ability of engineering thinking and obtain confidence to solve problems.

DISCUSSION
STEM Education integrated with PBL has significant influence on students about their positive attitudes towards innovative thinking and scientific inquiry ability. The study suggested that educators could design appropriate STEM activity integrated with PBL to raise
students’ ability to solve problems, and to facilitate abilities, which is essential to students’ future development.

Nevertheless, the application of STEM Education integrated with PBL is relatively lacking, and there are more areas to explore in the area. Teachers could design more practical activities that students can use crosscutting concepts to solve problems in the real world.

REFERENCES


FOSTERING SCIENTIFIC GRAPHING SKILL OF 7TH GRADE STUDENTS THROUGH WEB-BASED INQUIRY LEARNING: A PILOT STUDY IN CHINA

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ABSTRACT

The ability to understand scientific graphs is a necessary skill for students to carry out scientific inquiry activities in middle school. This study aims at validating the feasibility and effect of applying Graphing Stories, a scientific inquiry learning project translated from WISE project repertory, in 7th grade in China. Twenty 7th grade students participated in a five-week study at a middle school in Beijing. Pre- and post-test was used to examine the effect according to the knowledge integration rubric (KI), and questionnaire and interviews were committed to capturing students and teachers' attitudes to the project. Results show that the Chinese version of Graphing Stories, modified from WISE, effectively improved students' ability to understand scientific graphs; and students' ability to criticize graphs is significantly improved in comprehension, critique, and construction items. Moreover, Chinese middle school teachers and students have positive attitudes toward WISE-based learning. Based on this study, teachers still need to provide appropriate support and guidance in the process of scientific inquiry project.

Keywords: Scientific graphs, graph understanding, WISE, inquiry learning, STEM

INTRODUCTION

Understanding scientific graphs and graphing scientific phenomena are crucial skills for students to participate in scientific learning. Developing students’ scientific graphing skills is particularly important during the middle school period (Lai et al., 2016). Many countries have begun to attach more importance to scientific graphing skills in the middle school. For example, the Next Generation Science Standards (NGSS) in the U.S. requires students to use graphing tools in the process of modelling, reasoning and communicating while using graphs in teaching to represent the relationships between core concepts (NGSS Lead States, 2013).

However, a large number of studies have shown that middle school students' graph comprehension ability and the status of graphing teaching are not optimistic (Song, 2005; Xu, 2016) students cannot master scientific graphing skills in math or science classes separately (Lai et al., 2016), and it is difficult for students to use graphs for learning and communication in scientific inquiry learning. Therefore, combining the mathematical and scientific features is important and necessary in the teaching.

Web-based Inquiry Science Environment (WISE) is the academic research platform developed by Professor Marcia C. Linn’s research team at UC Berkeley, which features the use of technology to enhance the effectiveness of STEM teaching (Linn, Slotta, Terashima, Stone, & Madhok, 2010). Graphing Stories is a scientific inquiry project integrating mathematics graphs and scientific concepts in the WISE platform. In the practical
experiment, *Graphing Stories* project can enhance students' ability to understand scientific graphs (Vitale, Lai, & Linn, 2017).

This paper aims to validate the feasibility and effect of applying *Graphing Stories* in China. There are three research questions as follows.

1. Will *Graphing Stories* project be suitable for 7th grade students in China?
2. Will *Graphing Stories* improve 7th grade students’ scientific graphing skills?
3. Will teachers and students accept WISE projects in China?

**LITERATURE REVIEW**

**Scientific graph understanding ability**

Unlike mathematical graphs, scientific graphs represent the connection between scientific concepts and scientific phenomena. Scientific graph understanding includes interpreting, critiquing and constructing graphs (Lai et al., 2016).

**States of student's scientific graph understanding**

Teachers always overestimate students' ability to understand graphs. However, scientific graph understanding is a complex and difficult skill, and students and even adults often make mistakes in interpreting graphs (Shah & Carpenter, 1995). Kim and Kim (2002) used the TOGS scale to test 539 Korean middle and high school students’ scientific graph ability, and found that students’ ability to construct graphs is much lower than interpret graphs. In China, the status of students’ understanding of scientific graphs is not optimistic. Song (2005) investigated 667 Chinese middle and high school students’ capacity to understand and construct graphs and found that it needed to be strengthened. Xu (2016) surveyed 218 middle school students and found that students’ had difficulty in relating graph features to scientific concepts.

The above studies suggest that the difficulties students have in understanding scientific graphs mainly include the fact that (1) it is difficult to establish linkages between the features of graphs and scientific concepts, (2) the ability to interpret and construct still needs to be improved.

**States of teaching scientific graphs**

In school teaching, the graph is not an independent discipline but a piece of other compulsory disciplines. Graph knowledge generally belongs to the category of mathematics, but in the mathematics classroom, teachers generally only teach the basic knowledge of the graph itself (such as coordinates, slope, etc.). Students rarely touch the scientific features of the graph in the mathematics class (such as units, science counting methods, etc.), which are exactly what graphs in science must have (Lai et al., 2016). In the science classroom, teachers pay more attention to the guidance of scientific knowledge and inquiry methods. When students have difficulties in reading graphs, it is difficult for teachers to give timely feedback and guidance. Therefore, students cannot accurately use graphs and understand the meaning of graphs when they use graph tools for scientific study and inquiry.

The same teaching problem exists in China, but the current study has not been so thorough. In summary, both the current situation of students' understanding of scientific graphs and teaching scientific graphs all show a strong demand for teaching scientific graphs.

**WISE and Graphing stories**

**WISE**

*Web-based Inquiry Science Environment (WISE)* is an online scientific inquiry platform featuring technology-enhanced STEM learning. This platform is guided by knowledge
integration, with the goal of cultivating students raising scientific questions, proposing scientific predictions, designing verification experiments, analysing scientific data, and drawing scientific conclusions, which is a new scientific inquiry education system supported by visualisation technology, dynamic simulation technology, and intelligent assessment technology. This platform has developed dozens of interdisciplinary scientific inquiry projects, creating an online and offline integrated learning environment for teachers and students in the 4th to 12th Grades throughout the world (Zhao & Zhu, 2009). Today, the scientific inquiry learning research and practice community centred on WISE has been formed, and these achievements of the research team have exerted important influence not only in the field of science education but also in the fields of learning science and education technology (Chen, Zhao, & Wang, 2018).

**Study of Graphing Stories Project**

Graphing Stories project aims at developing students’ ability to analyse and solve problems through graphic problems in the scientific situation. Students can not only interpret graphs and construct graphs in scientific inquiry but also use graphs to solve scientific questions. Lai et al. (2016) used the GGI scale to test more than 460 U.S. middle school students’ ability of graph comprehension, and found that using KI scoring rubric to measure students' scientific graph understanding ability is effective. Vitale et al. (2017) studied the effect of students using the Graphing Stories project and concluded that students showed overall benefits. In China, the Graphing Stories project was launched for the first time, so there is no corresponding research in China currently.

**RESEARCH DESIGN**

**Participants**

This study was conducted in a middle school in Beijing, China, involving 20 7th grade students (age 12-13, 16 males and 4 females) who enrolled the school-based optional course Inquiry Learning. Since this was the first time that the school adopted the WISE projects, researchers were invited to give the classes a demonstration. Three in-charge teachers (two physics teachers and one ICT teacher) observed the whole procedure.

**Materials**

The Graphing Stories project (http://wise.berkeley.edu/project/21402#/vle/node2), developed by the WISE Research Group at UC Berkeley, and was translated into Chinese by the researchers. The original 10-hour project was designed for 8th grade students in the United States. Since 7th grade students participated in this study and only 5 hours was given to complete the project, amendments had been given to the original project by deleting the scenarios of Swimming and Mountain Climbing. The structure of the revised project (http://wise.bnu.edu.cn/project/189#/vle/node1) is shown in Table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Graphing Item</th>
<th>About</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Graphing in Science</td>
<td>Introduce the concept of scientific graphs by example to allow students to think about the relationship between graphs and scientific concepts. This activity contains 6 sub-steps, numbered 1.1-1.6.</td>
</tr>
</tbody>
</table>
2 Graph common mistakes  Exploring and correcting common mistakes in the reading and drafting process. This activity contains 8 sub-steps, numbered 2.1-2.8.

3 Amusement Park Challenge!  A computer simulation model is provided to learn scientific concepts related to acceleration and curvature by setting the characteristics (speed and direction) of the amusement park trolley. This activity includes 11 sub-steps, numbered 3.1-3.11.

**Measures**

The pretest and posttest items are selected from Graphing Inventory Fall 2017 (GGI). We designed the classification of graph understanding based on GGI (Lai et al., 2016), and selected 3 items to explain the students' comprehension, critique, and construction ability of the graph. Moreover, The pretest and posttest items were scored according to the knowledge integration rubric (see Table 2), which has been used in previous graphing applications (Vitale et al., 2015).

Based on the research purpose, this study developed the questionnaire on the application attitudes as the evaluation and improvement reference for WISE. The questionnaire contains seven questions. With Likert-type five scale, 5 points represent a positive attitude of students using WISE to learn scientific knowledge, while 1 point represents a complete non-conformity.

The interview protocol included questions about their experiences, feelings of inquiring with WISE and their willingness to do next project.

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Irrelevant; Off task</td>
</tr>
<tr>
<td>2</td>
<td>Invalid scientific ideas: overly vague</td>
</tr>
<tr>
<td>3</td>
<td>Partial link; Isolated normative idea</td>
</tr>
<tr>
<td>4</td>
<td>One link between two valid scientific ideas</td>
</tr>
<tr>
<td>5</td>
<td>Two or more links between three or more scientific ideas</td>
</tr>
</tbody>
</table>

**Procedure**

Students began the study by completing an individual, timed (30-minute) pretest. Following the pretest, twenty students were divided into ten groups, and two students shared a computer for collaborative learning. During the five-week course, students were given one hour of classroom work per week. When they completed the course, students immediately completed the posttest independently. Moreover, the attitude questionnaire was embedded at the end of posttest. Finally, ten students and three teachers were interviewed.

**RESULTS AND DISCUSSION**

**Student graph understanding**

Students’ performance on graph understanding in Table 3 shows, students’ total scores from pretest (M = 19.93, SD = 3.27) to posttest (M = 21.53, SD = 2.46). The paired sample t test results showed that there was a significant difference between the pretest and posttest results (t=-2.570, p<.05). Moreover, the result of students’ performance on the single-choice
questions and constructed-response question are different. The analysis show that there is no significant difference on the single-choice questions (pretest: M=5.05, posttest: M=5.45, out of 6 points), but in the answer to the constructed-response question, the student's score was evenly raised from 14.88 in the pretest to 16.08 in the posttest, and there was a significant difference (t=−2.379, p<.05).

These suggests that after completing the study of Graphing Stories project, students have achieved a significant improvement in their overall scores, especially in terms of graph interpretation capabilities. So students participating in the study have a certain ability to understand the graphs, but the ability to explain graphs still needs improvement.

### Table 3. Pretest and posttest performance

<table>
<thead>
<tr>
<th>Types</th>
<th>N</th>
<th>Pretest</th>
<th>Posttest</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
</tr>
<tr>
<td>total</td>
<td>20</td>
<td>19.93</td>
<td>3.27</td>
<td>21.53</td>
</tr>
<tr>
<td>single-choice</td>
<td>20</td>
<td>5.05</td>
<td>0.76</td>
<td>5.45</td>
</tr>
<tr>
<td>constructed-response</td>
<td>20</td>
<td>14.88</td>
<td>2.64</td>
<td>16.08</td>
</tr>
</tbody>
</table>

* p<.05

### Comprehension, critique, and construction

We conducted further paired sample t test to know whether students' performance differed by constructed-response item type, including comprehension, critique, and construction. We selected the race, climate change, and two cups of water items in the pretest and posttest to analyse performance on illustrative comprehension, critique, and construction. As a result, there is only significant differences in the critique item (t=−2.465, p<.05). The grade of comprehension and construction items have only slightly improved (see Table 4).

The comprehension item Race asks students to predict who will win the match and interpret according to the position and time graph (Fig. 1). We found that the accuracy of single-choice items for students to make predictions is high (pretest mean=2.30, posttest mean=2.90, out of 3 points). However, when interpreting, they are used to using computational data, rather than observing the characteristics of the graph. It is inconsistent with the ability of the KI rubric investigation, so the scores are not too high.

### Table 4. Comparison by item type (Out of 5 points)

| Types | N  | Comprehension | Posttest | | Construction |
|-------|----|---------------|----------| |---------------|
|       |    | Mean | S.D. | t   | Mean | S.D. | t     | Mean | S.D. | t    |
| Pretest | 20 | 2.80 | 0.64 | -0.131 | 2.98 | 0.95 | -2.465* | 4.03 | 0.94 | -0.698 |
| Posttest | 20 | 2.83 | 0.71 | 3.50 | 0.49 | 4.23 | 1.01 |    |       |       |

* p<.05

On the whole, Chinese students’ performance on comprehension and construction is acceptable, especially construction item (pretest mean=4.03, posttest mean=4.23, out of 5 points). At the same time, we also need to pay attention to the fact that Chinese students still have much room for improvement in their ability to criticise graphs (pretest mean=2.98, posttest mean=3.50, out of 5 points). What’s more, student should strengthen the concept of
knowledge integration, instead of just recognising the graph from a mathematical point of view.

![Graph](image)

**Figure 1. The table of graph construction item race**

**Student Feedback**

Table 5 shows the descriptive statistics of student feedback on the questionnaires. 19 of the 20 students who participated in the study completed the attitude survey. The results indicate that students showed a positive attitude towards scientific learning based on the WISE platform, in which students showed increased interest in learning science (Mean=4.42), and that WISE-based open questions and answer questions were helpful for their scientific thinking ability (Mean=4.21). In addition, students did not feel that they could not adapt to learning the rhythm of learning (Mean = 1.84), and felt that science learning was not just a matter of mastering the test (Mean = 2.16).

With regard to the willingness to use WISE platform, two open questions have also been set as follows "Do you think the WISE platform's learning method is suitable for you, and why?" and "Would you like to continue to use the WISE platform to learn scientific knowledge? Why?" Among them, 17 students from 19 students think that WISE platform is suitable for learning. One of the two unsuitable students thinks that he is not good at graphs, and the other student emphasises that because of his obsessive-compulsive disorder, he is not very good at utilising drawing tools. However, 19 students expressed their willingness to continue using the WISE platform for learning.

<table>
<thead>
<tr>
<th>Question</th>
<th>N</th>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>My scientific thinking skills benefited from the open-ended questions embedded in WISE project benefit.</td>
<td>19</td>
<td>4.21</td>
<td>1.08</td>
</tr>
<tr>
<td>*Exploring a scientific problem is too far away from me. I just need to master scientific knowledge needed for the exam.</td>
<td>19</td>
<td>2.16</td>
<td>1.12</td>
</tr>
<tr>
<td>I think it is easy for me to learn how to operate various tools in WISE.</td>
<td>19</td>
<td>4.26</td>
<td>0.99</td>
</tr>
<tr>
<td>I feel that I can perform various tasks in WISE.</td>
<td>19</td>
<td>3.79</td>
<td>0.98</td>
</tr>
<tr>
<td>I am more interested in learning science now.</td>
<td>19</td>
<td>4.42</td>
<td>0.84</td>
</tr>
<tr>
<td>I am willing to spend time thinking about various scientific issues in WISE.</td>
<td>19</td>
<td>4.00</td>
<td>0.94</td>
</tr>
</tbody>
</table>
*Learning WISE's project requires me to control the pace of learning. It makes me feel a bit confused.

* Negative question

**CONCLUSION**

The conclusions are as follows: (1) the Graphing Stories project can promote Chinese middle school students’ understanding of science graphs, (2) students have improved their ability in interpreting, critiquing and constructing items, and the ability of critical graphs has increased significantly, (3) Chinese middle school teachers and students have a high degree of recognition of WISE Graphing Stories project and are willing to conduct scientific inquiry learning. In summary, the WISE Graphing Stories project is adapted to Chinese middle school students.

However, we also found some problems during the project development. According to interview results and classroom observations, students’ interest and enthusiasm for the scientific inquiry project cannot be maintained. Moreover, students still generally ask teachers, although students can carry out their own learning. Therefore, in order to make middle school students in China more adaptable to the Graphing Stories project, teachers still need to consider the students' psychological and learning characteristics, and provide appropriate support and guidance in the process of the project when middle school students in China conduct online scientific inquiry learning.

**REFERENCES**

RESEARCH ON 3D PRINTED CREATIONS THROUGH COURSE DESIGN FOR THE DEMOCRATISATION OF PRODUCTION: INTERDISCIPLINARY OPPORTUNITIES FOR STEAM EDUCATION

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Australia
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ABSTRACT

Despite the abundant studies concerning the application of 3D printing in STEAM education, there is rarely research on 3D printed creations. With regard to manufacturing, participators in STEAM education are engaged in the democratisation of production (DOP) within the 3D printing supply chain, when those creations are used as practical products. Is it possible to involve the conception of the DOP in STEAM education through 3D printing supply chain, where students learn by applying 3D printers in fabrication of everyday life? In order to solve this research question, four theoretical models were employed to construct a systematic framework that leads to an integrated research design. Qualitative research was applied to identify five types of 3D printed creations. Then, a case study was employed to understand different mechanisms of the creations’ types. It was found that the type of CAD learning project objectively fulfilled the DOP. In addition, 3D printed creations could become practical products if they are planned with a functional purpose. Based on these findings, a CAD-based STEAM class was designed through ADDIE model and implemented to a group of middle school students in China. The possibility in developing STEAM courses for the DOP within a 3D printing supply chain was verified in the tracking survey. In conclusion, this research established a theoretical model of fabricating practical products through CAD-based STEAM class. This model illustrates interdisciplinary opportunities for STEAM education, product design, and manufacturing industry.

Keywords: STEAM education, 3D printed creations, 3D printing, supply chain, democratisation of manufacturing, product design

INTRODUCTION

Background and Literature Review

The rise of affordable 3D printing plays one of the most important roles in shaping the education of science, technology, engineering, art and math (STEAM). 3D printing is often utilised to make small plastic objects. STEAM teachers typically apply desktop 3D printers to evoke students’ interest in learning (Irwin, 2015). A number of companies associated with 3D printing have also released educational programs for creativity development. For example, Dremel expands STEAM education opportunities by a digital ecosystem MyStemKits (www.mystemkits.com) that provides 3D printing lesson plans, software, and equipment.

3D printing used in education facilitates the democratisation of invention (Blikstein, 2013), which is beyond fostering STEAM interest and promoting learning system. The
democratisation of invention refers to an emerging model of product development where either designers or K-12 students are able to create working prototypes by rapid prototyping equipment like 3D printers. A growing proliferation of 3D printers has caused a blossom of utopian views towards personal fabrication (Mota, 2011). This conception goes along with spreading of STEAM education because 3D printing has the potential to foster user-driven innovation and creativity (von Rekowski, Boden, Stickel, Hornung, & Stevens, 2014). Hence, Bull and Groves (2009) suggested that young students can use Computer-aided Design (CAD) and Computer-aided Manufacturing (CAM) to see how their ideas get transformed from concept to physical form.

Despite the wide range of applications of 3D printer which is used as a tool in STEAM education, there is rarely research on 3D printed creations that the tangible outcomes generated through CAM. Here the creations contain all physical objects made by participants who use 3D printers at the STEAM class. The equipment is normally based on Fused Deposition Modelling (FDM), Stereo Lithography Apparatus (SLA), or Digital Light Processing (DLP).

Based on the scenarios, the role of 3D printed creations is transformed to practical products from invention prototypes. For example, a student designs and 3D prints a vase. After that, he or she places the outcome as a decoration on the dining table. Notably, the student makes the 3D printed work for the real world. Thus, 3D printing not only facilitates the democratised development, but also signifies the Democratisation of Production (DOP) from the perspective of manufacturing. “While 3D printing is at the center of the democratised production process, there have been developments in all elements of the DIY manufacturing lifecycle ...” (Koff & Gustafson, 2012, p. 17). These elements make STEAM teachers and students actual manufacturers.

As a result, these 3D printing users and their creations are addressed in the future supply chain. Supply chain is defined as a system that involves the transformation of natural resources, raw materials, and components into a product or a service provided for customers (Kozlenkova, Hult, Lund, Mena, & Kekec, 2015). 3D printing enables anyone with a digital design, such as teachers or students in STEAM education, “to bypass the traditional supply chain and manufacture a product by themselves” (Koff & Gustafson, 2012, p.15). In addition, open source expands the 3D printing supply chain in dynamic and online communities. Notable examples are those educational projects shared on Thingiverse.com, where teachers and students benefit from free digital models; and they will likely contribute back to the platform. In this process, 3D printing drives proactive production and distribution of products.

**Gap, Question, and Potential Benefits**

Based on the above critical review, the author identified a research gap between the utilisation of 3D printers in STEAM education and the DOP within 3D printing supply chain. In order to bridge the gap, the research question about “is it possible to involve the conception of the DOP in STEAM education through 3D printing supply chain, where students learn by using 3D printers to make practical products for everyday life” is addressed. As this study focuses on education, design, and manufacturing, research findings could bring potential benefits to organisers and participants of STEAM education, product designers dedicated to product innovation, and manufacturers of educational products, toys, accessories, etc.

**Research goal and objectives**

The research aims to explore the possibility of developing STEAM courses for the DOP within the 3D printing supply chain. Key research objectives include (i) to identify different
types of 3D printed creations fabricated in existing STEAM courses, (ii) to investigate mechanisms of those 3D printed creation’s types, and (iii) to design and implement a STEAM class based on above findings, in which the DOP within 3D supply chain is probably facilitated.

**Theoretical framework**

Four theoretical models were employed to construct a systematic framework. Fig. 1 shows the general 3D printing process. Firstly, 3D models are fed to CAD software for creating 3D printable files, which are then transformed to 2D slices. In the end, the slices are sent to the 3D printer for the building of the physical object (Zhang, Dong, & Saddik, 2016).

![Figure 1. General 3D printing process](image1)

As shown in Fig. 2, both the second and third theoretical models are regarding supply chain of physical products. “A direct supply chain consists of a company, a supplier, and a customer involved in the upstream and/or down-stream flows of products, services, finances, and/or information” (Mentzer et al., 2011, p. 4). Raw materials sent from suppliers are transformed into final products through prototype, manufacture, and assembly. Manufacturers distribute the products to warehouses and then deliver them to customers through retailer channels. On the contrary, 3D printing enables people with digital designs to manufacture products by themselves via a direct chain (Koff & Gustafson, 2012).

![Figure 2. Traditional supply chain and 3D printing supply chain](image2)

Fig. 3 illustrates an ADDIE course design model, a descriptive guideline for building teaching support tools in five phases including analysis, design, development, implementation, and evaluation (Branch, 2009). In this research, ADDIE model is utilised to organise a STEAM class associated with 3D printing.
Based on above models, a theoretical framework of this study is developed. As proposed by the author, when the general 3D printing process is engaged in a STEAM class through the ADDIE model, teachers and students obviously facilitate the DOP within the 3D printing supply chain.

METHODOLOGY

Research Design

A research design is created for answering the key question of this study. Namely, is it possible to involve the DOP in STEAM class through 3D printing supply chain? The research process is divided into three sections. In the first section, qualitative research is applied for identifying 3D printed creations’ type. The author studied the research objects and generate descriptive results. Three steps of this section include searching 3D printed creations, categorising the creations, and identifying the type.

In order to understand different mechanisms of the creations’ types, case study is adopted in the second section, as it is suitable to an exploratory research process which aims to answer the “how” questions (Yin, 1994). Currently, there are a considerable number of STEAM courses concerning 3D printing. Therefore, a multiple-case holistic design is employed. Its first two steps describes preparing for evidences collection and collecting evidences. Step three concludes the findings through evidence analysis.

Based on one selected mechanism in the third section, the author designed and implemented a STEAM class. Research through Design (RTD) is applied as the method, because it represents a concept that describes an approach in which the design process acts as a way for acquiring genuine knowledge (Frankel & Racine, 2010). The term “design” has a double meanings, namely course design and product design. Course is designed to achieve related objectives based on the ADDIE model, and product is designed to become the expected creations for either STEAM class or the DOP. Then, the author carried out a tracking survey to describe how these outcomes work in life. Related results are presented and discussed in the next chapter. As RTD seeks to provide theory, the author finally concluded a theoretical model of building a STEAM class for the DOP within the 3D printing supply chain.

Qualitative Research on the Types of 3D Printed Creations in STEAM Courses

Searching 3D Printed Creations

The author searched 50 creation samples from corresponding 3D printing lesson plans, which are provided by three of the most typical STEAM education systems, namely Dremel Digital Lab (digilab.dremel.com), Thingiverse Education (www.thingiverse.com/education), and MyStemKits mentioned above. They all provides abundant lessons that make STEAM classes with 3D printers for various subjects and levels (see Fig. 4).
Categorising 3D Printed Creations

The author has categorised 50 searched creations according to fabrication purposes. For example, some of these creations are 3D printed as educational products for visualising the knowledge of science and mathematics.

Identifying the Type of 3D Printed Creations

Table 1 displays five identified types of 3D printed creations, including educational products, other products, CAD learning projects, 3D printer learning projects, and engineering objects. In addition, features of each type are described in details.

<table>
<thead>
<tr>
<th>Numbers</th>
<th>Categories</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Educational Product</td>
<td>Related creations are 3D printed for visualising the knowledge, e.g. 3D printed chemical models that allow students to make physical interaction.</td>
</tr>
<tr>
<td>Type 2</td>
<td>Other Product</td>
<td>Related creations are 3D printed for application in real scenarios, e.g. 3D printed stationary.</td>
</tr>
<tr>
<td>Type 3</td>
<td>CAD Learning Project</td>
<td>Related creations are 3D printed as the tangible results of learning of CAD software, e.g. picture frames fabricated through measurement, design, digital modelling, and 3D printing in CAD class.</td>
</tr>
<tr>
<td>Type 4</td>
<td>3D Printer Learning Project</td>
<td>Related creations are 3D printed as the tangible results in learning of 3D printer use, e.g. drinking cups fabricated with the FDM 3D printer.</td>
</tr>
<tr>
<td>Type 5</td>
<td>Engineering Object</td>
<td>Related creations are 3D printed for achieving specific engineering objectives, e.g. 3D printed battery cases applied for electrical circuits.</td>
</tr>
</tbody>
</table>

Case Study on the Mechanisms of 3D Printed Creations in STEAM Courses

Preparing Evidences Collection

In this section, the author carried out a case study to figure out how different types of 3D printed creations are facilitated. In order to prepare evidence collection, first of all, five typical cases that stand for each type were selected from 50 searched samples (see Table 2). Secondly, the author draught the formulation of the evidence-collecting procedure, wherein
two questions are proposed. Who design, model, and then 3D-print the creations? Whether these creations are used as practical products in life?

Table 2. Selected case study samples

<table>
<thead>
<tr>
<th>Numbers</th>
<th>Samples</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Chemical Modelling</td>
<td><a href="https://www.thingiverse.com/thing:2134356">https://www.thingiverse.com/thing:2134356</a></td>
</tr>
<tr>
<td>Type 2</td>
<td>Measurements Kit</td>
<td><a href="https://digilab.dremel.com/resources/lesson-plans">https://digilab.dremel.com/resources/lesson-plans</a></td>
</tr>
<tr>
<td>Type 3</td>
<td>Modular Frame</td>
<td><a href="https://digilab.dremel.com/resources/lesson-plans">https://digilab.dremel.com/resources/lesson-plans</a></td>
</tr>
<tr>
<td>Type 4</td>
<td>Nameplate</td>
<td><a href="https://www.thingiverse.com/thing:876282">https://www.thingiverse.com/thing:876282</a></td>
</tr>
<tr>
<td>Type 5</td>
<td>Modular Robot</td>
<td><a href="https://www.thingiverse.com/thing:2662828">https://www.thingiverse.com/thing:2662828</a></td>
</tr>
</tbody>
</table>

Collecting the Evidences

Table 3 displays the evidences of the mechanism of each 3D printed creation type.

Table 3. Mechanism of five types of 3D printed creation

<table>
<thead>
<tr>
<th>Samples</th>
<th>Who?</th>
<th>Whether Used as Practical Products?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design</td>
<td>Model</td>
</tr>
<tr>
<td>Chemical Modeling</td>
<td>Lesson Plan Developers</td>
<td>Lesson Plan Developers</td>
</tr>
<tr>
<td>Measurements Kit</td>
<td>Lesson Plan Developers</td>
<td>Lesson Plan Developers</td>
</tr>
<tr>
<td>Modular Frame</td>
<td>Students</td>
<td>Students</td>
</tr>
<tr>
<td>Nameplate</td>
<td>Lesson Plan Developers</td>
<td>Lesson Plan Developers</td>
</tr>
<tr>
<td>Modular Robot</td>
<td>Lesson Plan Developers</td>
<td>Lesson Plan Developers</td>
</tr>
</tbody>
</table>

Analysing the Evidences for Findings

These evidences were analysed for an understanding of the mechanisms of different 3D printed creation types. Firstly, except for the objects designed by students in the Modular Frame project, the other four types of creations are designed and provided by a lesson plan developer. Secondly, only the design in the Modular Frame project is modelled by students, while the designs of other four samples are provided by lesson plan developers. Thirdly, all these five types of creations are 3D printed by students. In the end, those creations facilitated in projects of Chemical Modelling and Modular Robot are not used as practical products, while the other three types of creations are facilitated for life.

The analysis above leads to two findings. In Type 3 of 3D printed creation (CAD Learning Project), students obviously fulfill the DOP within the 3D printing supply chain, as they practise a completed 3D printing process and finally output products for the real world. Furthermore, most 3D printed creations can be transformed into practical products, if they are planed with a functional purpose by a lesson plan developer.

Research through Course Design for the DOP within 3D Printing Supply Chain

Designing a STEAM class

According to the above findings, the author designed a class to explore the DOP within a 3D printing supply chain in STEAM education. Type 3 of 3D printed creation was selected as class outcomes, as this type enables students to facilitate the DOP through 3D printing. As shown in Fig. 5, a plug-pulling tool was designed and translated to a CAD-based STEAM
class, where TinkerCAD modeling software is applied. In the end, the ADDIE model was used to organise a STEAM lesson plan.

![Figure 5. CAD-based STEAM Class: Plug-pulling tool](image)

Implementing a STEAM class
This CAD-based STEAM class was implemented for 32 middle school students at Nanjing Foreign Language School Xianlin Campus, which is located in Nanjing city, Jiangsu Province of China. Two teachers together with the author guided those students to complete their projects.

Tracking Survey of 3D Printed Creations
The author continued to track the application of the plug-pulling tools at students’ homes. According to survey evidence, these fabricated tools indeed are installed for termination. These class outcomes are positively welcomed by students’ family members.

RESULTS AND DISCUSSION
As a result, the author proved the possibility in developing STEAM courses for the DOP within a 3D printing supply chain, where students participate in the CAD-based STEAM class to fabricate practical products. This result means that many questions arise from the possibility. Discussion and answers of these questions will require the collaborated attention of researchers from various fields including STEAM education, product design, manufacturing industry, etc.

- How to develop students’ creative thinking through the CAD-based STEAM class for the DOP?
- How to engage product designers in development of the CAD-based STEAM class for the DOP?
- Is it possible to involve manufacturers or brands in the CAD-based STEAM class for the DOP?
- How to evaluate the value of CAD-based STEAM class for the DOP for involved sides?

CONCLUSION AND SIGNIFICANCE OF THE STUDY
In conclusion, a theoretical model concerning developing STEAM courses for the DOP within the 3D printing supply chain was conducted (see Fig. 6). In the context of the DOP, 3D printing supply chain with three stages is facilitated through the CAD-based STEAM class. At the development stage, the class is designed based on the ADDIE model to generate a lesson plan. STEAM educator, product designer, or manufacturer is probably engaged as
collective developers. Then, the second stage consists of designing, modeling and 3D printing, in which students fabricate projects through a general 3D printing process. At the third stage, fabricated projects are used in life as real products. This theoretical model significantly illustrates interdisciplinary opportunities for not only the STEAM education, but also the product design and manufacturing industry.

**Figure 6. Model of developing the democratisation of production through CAD-based STEAM class**

**REFERENCE**


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A STEM CURRICULUM DESIGN THAT COMBINES VIRTUAL AND REALISTIC SITUATIONS

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ABSTRACT

STEM teaching guides students through the complex situational issues to complete the project. At present, the content of STEM curriculum is independent, and there is no story line of professional situations. Situational introduction is also mostly a linguistic description. Students lack the experience of professional characters. PSAA is abbreviation of a technology-enhanced problem-solving ability assessment system that can track how students solve problems by analysing their reading behaviours. It has the ability to introduce problem situations. This paper studies how to use PSAA system to design virtual problem situation of STEM education. Five-point scale was compiled to collect student feedback. By running a series of experiments with a total of 338 elementary and middle school students in Beijing, we found that 149 students to use the PSAA system very much to complete the task, accounting for 44.08%.

Keywords: Problem Situation, STEM Education

INTRODUCTION

Knowledge is situational. It is a part of activities, backgrounds and cultural products, and is constantly being used and developed in a rich context (Brown, Collins, & Duguid, 1989).

Learning needs situations, only to be placed in a specific situation to learn meaningful (Jonassen, 2000). In order to understand learning, cultural backgrounds of learning need to be considered. Situational learning requires learners to participate in genuine cultural practices, and consider participation as an important feature of learning. It also requires learners to participate in the construction of meaning and identity through the constant interaction of understanding and experience (Wenjing, 2005).

Creating problem situations is the source of motivating students' thinking. It is also a bridge to achieve teacher-student interaction in the process of STEM teaching and promotes students' independent learning. Problem situations motivate students to form a strong desire to explore and solve problems, and stimulate learning motivation. Problem situations can guide students to actively participate in interdisciplinary learning activities and cultivate the ability to independently think, analyse, and solve problems. The problem situation is the link between theory and practice; it promotes meaningful learning, and cultivate students' ability to creatively solve problems (Chunli, 2003).

STEM education is multidisciplinary. Most teaching activities use PBL (project-based learning) as a teaching method. “The learner is immersed in the scene, learning through active learning, collaborative inquiry learning, and experiencing the entire process from
clarifying problems to solving problems. In PBL, students are expected to learn by solving problems” (Lishan, Shengquan, Baoping & Jing, 2017).

The STEM curriculum in practical teaching is often complex, and it brings a lot of cognitive load to the students. The problem situation provides suitable materials and inspiring questions that are easy to ask, and guides the learner to complete the project (Yan, 2016). The design of the STEM problem context is not continuous and lacks plot linkage. Situational introductions are mostly linguistic descriptions. Insert a simple job description and lack the contextual experience of the professional.

Computer technology can simulate and create situations that solve problems. PSAA system is the abbreviation for a technology-enhanced problem-solving ability assessment system that can track how students solve problems by analysing their reading behaviours. It has the ability to introduce problem situations.

This paper studies how to use a PSAA system to design virtual problem situation of STEM education; integrate PSAA system with real PBL, combining the actual situation with the virtual situation, design PBL curriculum with a storyline and virtual career experience.

PROBLEM SITUATION DESIGN IDEAS

Knowledge as a tool for problem solving

Situational learning theory uses knowledge as a tool. Tools and knowledge share several important characteristics; they can only be fully understood through the use of their talents. Their application must both change the user's perception of the world and must adapt to the culture's belief system (Brown, Collins, & Duguid, 1989).

Situational characteristics are authentic. The problem scenario of STEM education is the background of project knowledge and skills, and it has a high degree of authenticity. The context of the problem is complex and requires students to systematically solve a series of related issues.

Connecting tasks with story lines

Most of the STEM curriculum are for the purpose of completing a certain engineering project. Most of the projects are independent and lack the necessary situational linkage. In a complex case, something can be called a “story point,” and the various things in tandem form a “story line”. Each project-based learning is seen as an independent story point. Each story point is connected into a complete story line. At the same time, evaluating the ability of student analysis, decision-making and problem solving is based on their interactive behaviour in the storyline.

STEM curriculum like Solar Rescue Vehicle, life detectors and simple generators can be done through three separate project-based learning. Connect tasks with a series of earthquake rescue scenarios.

Create a professional background for the task

One of the goals of STEM education is to hope that students will be more engaged in STEM-related work areas and improve national science and technology competitiveness. The purpose of the curriculum is to guide students to understand the characteristics of their profession and the work they will do. Students have more professional experience in the task.

Students can understand the nature of the job, the workflow, and the issues that need to be resolved. In the above case, students play the same role as the players in the game and complete the tasks as an earthquake rescue team.
Create virtual problem situations using computer technology

“Tools such as MicroDYN and MicroFIN have proved to be trustworthy in assessing complex problem-solving performances in the dynamic environments representing linear structural equations and finite state automata” (Lishan et al., 2017). PSAA is a test system. It has the following features: (1) Test items that are close to life situations; (2) Simulate real life situations to test students' practical problem solving skills; (3) Study student behavioural data during operation to form a problem solving capability diagnostic information.

The system has written a series of test items that are close to real life. There is a tracker, an interactive behaviour recorder, and a general-purpose control “Data Center”. Students can learn relevant new concepts as needed and answer a series of multiple choice questions, and questions raised in the context of interactive learning to complete the test. During the system test, students learn materials and answer the questions raised in the interactive situation. The "Data Center" is always open, and the system backstage also records the student's operation process. In the results feedback session, the learning result report is generated according to the student's answer. The report content includes the student's answer score and the interpretation of problem solving ability model. It collects student operating process behaviours data to generate student problem solving capability information.

DESIGN VIRTUAL SITUATION FOR STEM CURRICULUM

According to China's comprehensive practical activity curriculum guidelines for primary and secondary schools, comprehensive practical activities are based on the student's real life and development needs, discovering problems from life situations, and cultivating students' comprehensive quality of interdisciplinary practical courses. The course emphasises that students use various subject knowledge comprehensively to recognise, analyse and solve real problems, and improve their overall quality. Students can gain professional experience. They refer to the students' internships in practical jobs or simulated situations, and recognise the process of professional roles.

The earthquake rescue story line connects three STEM courses, namely solar rescue vehicles, life detectors and simple generators. Due to the difficulty in simulating earthquake rescue in real environments, the character of the earthquake rescue team was designed to set up sub-tasks for earthquake rescue that need to solve problems. The earthquake disaster has caused great harm to the homeland of human life. Many international rescue teams have played an important role in earthquake rescue work.

The earthquake rescue work project includes 8 tasks: (1) Rescue material preparation, production of solar rescue vehicles and life detectors; (2) Sort earthquake rescue incidents; (3) Emergency response; (4) Medical rescue; (5) Repair the road; (6) Communication power protection, making temporary generators; (7) Food and material security; (8) Sorting of secondary events. Task 1 and 6 are actual hands-on STEM projects in the form of PBL, and the others are required to complete a virtual problem-solving task on the PSAA test system.

Items objective: To operate the PSAA test system to experience the earthquake rescue work so that students can experience the process carried out by the earthquake rescue team in solving the problem. By designing and manufacturing earthquake rescue tools (solar rescue vehicles, life detectors, and simple generators), STEM-related capabilities are developed, and student behaviour data is collected and analysed through the PSAA test system to evaluate students' ability to solve problems.
**Subtask settings**

Natural disasters can occur anywhere in the world. Earthquakes, floods and extreme weather can all cause great damage to people’s lives. Traffic is destroyed, while food, water, and housing sites are difficult to obtain. When an earthquake occurs, there needs to be a good response in arranging self-rescue and rescue activities in order to effectively reduce losses.

**Task 1.**

Prepare relief supplies. This is a STEM project that requires practical hands-on production of solar rescue vehicles and life detectors.

**Task 2.**

Ordering of events. At 8:30 AM on June 17th, an earthquake occurred in Nicaro. Please choose the order of handling matters according to the judgment of the critical situation. Use the "Data Center" to learn to submit answers in the PSAA test system.

**Task 3.**

Emergency response. The emergency plan for earthquake disasters is to coordinate, orderly and efficiently conduct earthquake emergency work, minimise human casualties, and reduce economic losses and social impact. According to the China Earthquake Emergency Plan, several levels of response measures should be initiated. Students need to use the PSAA “data Center” to complete the task.

**Task 4.**

Medical assistance.

**Subtask 4.1 Rescue route selection**

Garment City was severely damaged in the earthquake. There are a large number of wounded who need emergency assistance. Medical personnel are now dispatched from the hospital. Please collect the required information and choose the fastest route! Students need to submit a driving route plan on the PSAA system. The system will record and analyse student behaviour data.

**Figure 1. Selecting a rescue route**

**Sub-task 4.2**

For emergency situations in which there are many casualties, and medical resources are insufficient, the simple triage and rapid treatment (START) is used to classify the wounded. Students need to use the “Data Center” to learn how to classify and mark the wounded.
Subtask 4.3 Predicts and estimates medical demand so that medical arrangements can be properly scheduled.
According to the accumulated earthquake casualty statistics chart, within six days of the earthquake, it was determined which day the injured person had the highest growth rate and the cumulative number of earthquake victims on the seventh day. Submit the result of the calculation in the PSAA system.

Task 5. Road restoration.
The traffic channel that connects with the outside world is sometimes referred to as the "life channel". Because of the entry of large-scale relief supplies, the transfer of injured persons requires the smooth flow of road traffic.

Subtask 5.1 Road Selection
Nicaro has only two roads connected to the outside world. They are Wutong Road, which is connected to Tanamo, and Huangshi Road, which is connected to Kiel. Now that you are the decision maker, depending on the degree of road damage and the efficiency of road construction, which road should the Nicaro engineering team repair first? How quickly can you get through? Submit calculations using the PSAA system.

Subtask 5.2 Estimated time
Three hours have passed since the earthquake. Assume that after comprehensive consideration, it was decided to repair Huangshi Road in order to better arrange for relief supplies, personnel entry, and the transfer of injured personnel. Estimate the time to repair the road and write your calculation method. Submit the calculated answer on the PSAA test system.


Subtask 6.1
As the earthquake destroyed the ground base stations and telecommunication cables, some hand-held satellite phones need to be airborne to the disaster area. Calculate the number of hand-held satellite phones based on demand calculations and use the PSAA test system to calculate and submit the answers.

Sub-task 6.2
Earthquakes have caused power interruptions in many places of the town of Cuxh. Restore the electricity supply in all areas of Cuxh town with the best plan. Students need to simulate the circuit maintenance process on the PSAA system.

Figure 3. Circuit maintenance

**Task 7. Food and Material Protection**

**Subtask 7.1**
The earthquake-damaged road is difficult to recover as soon as possible. Rescue workers plan to use helicopters to transport food and water for one day to the disaster area. The number of parcels a plane can deliver is limited. Which information is needed to calculate the amount of food and water delivered? Use the PSAA system to select the required information.

**Subtask 7.2** Select the flight line. The relief supplies are to be airdropped to the five towns named ABCDE before dark. It is required to complete the flight line selection on the PSAA system.

Figure 4. Select the flight line
Subtask 7.3 loading program

In the evening, it was suddenly heard that there was a village in Bonn that was seriously affected and needed immediate delivery of food and water for the next day. According to the actual situation, how many packages of food and water will be supplied in this car to meet the needs of people in Bonn as far as possible? Explain your reasons. You can use the “Data Center”, "Tool Center", and "Experiment Center" to complete the task.

Task 8. You have completed all the challenges in this project, please select the order of processing according to the severity of the matter.

After completing the task, the PSAA system can generate a test report of the student's problem solving skills.

RESULTS AND DISCUSSION

The PSAA system has been tested at Beijing Jingshan School and the second affiliated secondary school of Beijing Normal University. A questionnaires was prepared to survey student satisfaction. Students were asked the following questions. Q1. Do you like to use PSAA to complete the task? Q2. Is the PSAA system easy to use? Q3. Can the evaluation report clearly assess the ability? Q4. Is the task interesting? The survey used a 5-point scale consisting of: very disliked, disliked, generally liked, loved and liked very much. The score ranges from 1 to 5.

This study obtained 338 valid questionnaires, including 171 boys, accounting for 50.59%, and 167 girls, accounting for 49.41%. Questionnaire data showed that 149 people indicated very liked to use the PSAA system to complete the task, accounting for 44.08%. There are 167 individuals who thought that the PSAA system was very easy to use,
accounting for 49.41%. It was thought that the evaluation report could clearly evaluate their own ability. The number was 139, accounting for 41.12%. The number of people who thought the task was very interesting was 122, accounting for 36.09%. The mean and standard deviation are shown in Table 1.

Table 1. The average score and variance of the four questions

<table>
<thead>
<tr>
<th>Question</th>
<th>Total number</th>
<th>Very disliked</th>
<th>Disliked</th>
<th>Generally liked</th>
<th>Liked</th>
<th>Very liked</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>338</td>
<td>19</td>
<td>9</td>
<td>99</td>
<td>62</td>
<td>149</td>
<td>3.93</td>
<td>1.180</td>
</tr>
<tr>
<td>Q2</td>
<td>338</td>
<td>12</td>
<td>15</td>
<td>52</td>
<td>92</td>
<td>167</td>
<td>4.14</td>
<td>1.082</td>
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<tr>
<td>Q3</td>
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<td>338</td>
<td>38</td>
<td>22</td>
<td>91</td>
<td>65</td>
<td>122</td>
<td>3.62</td>
<td>1.326</td>
</tr>
</tbody>
</table>

The reason is that the assessment method of PSAA is novel in China and is different from the traditional paper-pencil test. The tasks are contextual and interesting. Tasks that are similar to games can arouse students' interest and can also obtain virtual professional experience.

The study clearly has several limitations. Firstly, the sample size is relatively small. Secondly, this research is not deep enough to introduce problem situation research, and the questionnaire setting is not hierarchical. Thirdly, this study is only an exploration of the STEM teaching situation introduction method. At present, there is still relatively little research on the effective combination of PSAA system and STEM education. This is an aspect of our future research.

REFERENCES


INNOVATIVE PRACTICES IN STATE SCHOOLING: ENGAGING DIVERSE AUDIENCES IN STEM BEYOND THE CLASSROOM

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ABSTRACT

This symposium will discuss a range of initiatives based on the DoE Schools of the future STEM Strategy. This strategy has three areas of focus:

- Building teacher capability to transform STEM learning
- Influencing more students to become engaged in STEM learning, and
- Achieving excellence in STEM learning

The panel will address issues of inclusion within STEM education by discussing light house programs that influence and transform the teaching and learning of STEM for rural and remote students, girls, indigenous students and young students identified as of superior IQ. These participatory practices focus on experiential, inquiry based pedagogies (including face to face, online and blended methodologies) and partnerships that support co creation of new knowledge.

This paper highlights four strategies that seek to increase engagement, academic performance, retention and participation in STEM based higher education and career opportunities within these underrepresented groups - providing them with the opportunities they need to develop as problem solvers, critical and creative thinkers:

- The Queensland Virtual Stem Academy
- Solid Pathways (Indigenous Outreach)
- DoE STEM Girl Power Camp, and
- The Queensland Academies Young Einstein’s Program

Evidence based decision making focused on design, impact, scalability and investment of these strategies will contribute to improved teacher capability and further transform STEM learning partnerships that and prepare young people for success in a knowledge-based economy.

Keywords: Inclusion, rural and remote, girls, indigenous students, gifted students, blended learning
ABSTRACTS

Symposium paper 1: What is the current state of STEM clubs in Queensland and how can quality programming be supported?

Background:
The University of Southern Queensland carried out an evaluation of the current state of STEM clubs in Queensland through a review of relevant literature and an analysis of data drawn from roundtable discussion and online surveys. This work assisted in establishing some of the most salient features of quality STEM clubs and their implementation. These features were grouped into the following broad categories:

- Characteristics of STEM clubs;
- Rationale and vision;
- Success factors;
- Start up and implementation;
- Barriers and challenges; and
- Resourcing.

These insight lead to the development and piloting of a framework to support new and existing STEM clubs to start-up or consolidate quality programming, respectively. The piloting process was undertaken by a representative sample of STEM clubs (e.g. location, type, participants, focus, etc.) across the state. The intention of the framework was for it become a tool to support STEM club success and sustainability.

Key Points:
- Provide insights, using the six categories from above, of the features of quality STEM clubs;
- Detail the processes used to develop and pilot the framework; and
- Invite comments and feedback on the framework as a potential tool for the creation and maintenance of quality STEM club programs.
Symposium paper 2: What is the value of community-based informal STEM learning opportunities such as STEM clubs?

Background:
Inspiring Australia is a national program focused on working towards a society critically engaged with the sciences. One aspect of the program in Queensland is science or STEM clubs, where informal and inquiry-based STEM learning can occur for all ages. There is no one single type of STEM club, but the vision for these clubs is that they are centred around local issues and ideas, connected with community, inquiry-based, hands-on and fun. They can also be run by anyone, with easily obtainable materials, calling in experts and resources where available. This project was developed to trial and evaluate many different types of STEM clubs across Queensland to gain a better understanding of what resources and models are most effective and sustainable in different situations, and inform the future support of STEM clubs in the State.

Key Points:
- Detail the types of STEM clubs that can be found across Queensland;
- Share the learning from the trialling and evaluation of different STEM club models; and
- Highlight the types of measure that could be considered to support effective and sustainable STEM club programming.

Symposium paper 3: Case study – STEM clubs in school settings

Background:
Nicola Flanagan is the Head of Innovation at Oakleigh State School. She has played a key role in the evolution of learning at her site over the last 6 years. This has included early implementation of the Digital Technologies Curriculum and an ever-evolving approach to inquiry within STEAM. One of the strategies to support her community of learners has been the implementation of “The Young Innovator Program” - an extra-curricular program which relies on partnerships with parents, the community and industry experts. The latest iteration has involved aligning this opportunity to professional learning for her teachers and the expansion into the cluster of 11 schools to which the school belongs.

Key Points:
- Describe the vision and intention of the “The Young Innovator Program” STEM club, including the impact on STEM learning;
- Share the benefits and challenges of forming partnerships (e.g. parents, community, industry) to enhance STEM club offerings; and
- Detail the impact on professional learning and expansion on the quality of the STEM club program.

Keywords: STEM clubs, informal learning settings, quality learning
ABSTRACTS

**Symposium paper 1:** Australia Pacific LNG STEM Central facility in Central Queensland

*Background:* The ConocoPhillips Science Experience is an event involving science experiences for Year 9 and 10 students in universities across Australia. In 2016, a university located in Central Queensland ran a local event. This event involved community and industry networks working together to create a suite of hands-on immersive sessions for the students. The success of this event and other partnerships developed in the area of STEM education over the past five years has resulted in the development of the Australia Pacific LNG STEM Central facility. This paper will be co-presented by a staff member from the university and a representative from ConocoPhillips.

*Key Points:* The Australia Pacific LNG STEM Central facility is an important addition to the regional community, providing access to resources and STEM education practices not commonly available or accessible. The facility consists of six “booths”, each one designed to be multi-purpose, allowing problem-based learning to occur. Incorporating science, technology, engineering design processes and mathematical concepts into an integrated project design has been used as the pedagogical approach. This is an important concept for primary teachers when embedding STEM into the classroom – “doing STEM” is not just about coding and robotics. The goal of the facility is to develop STEM knowledge and embed STEM in schools and the community through the implementation of a series of workshops and activities for teachers and community leaders.

**Symposium paper 2:** STEM Partnerships in Community Hackerspaces and Makerspaces

*Background:* The presenter of this paper works closely in the development of hackerspaces and makerspaces for those in the over 18 demographic,
including university students and DIY enthusiasts. As the Community Engagement Coordinator at a local university and the Patron of a local Hackerspace, she has developed a range of industry and community partnerships in these spaces for mutual benefit.

Key Points:
The presenter will discuss success stories and the potential of collaborative projects in these spaces. This includes partnerships in the areas of upcycling, upskilling, entrepreneurship, mental health and large-scale artwork/sculpture development. She will elaborate on how to leverage these partnerships for greater mutual benefit and how to start your own partnerships with local community groups. The presenter will also discuss how schools can improve their STEM offerings through similar partnerships, detailing what works well and what to avoid.

Symposium paper 3: The great divide, building relationships with the community and teachers in the classroom

Background:
Agriculture is often viewed as working and living on the farm. The extent that agriculture impacts on the daily life of students through the technologies that are needed to ensure sustainable food and fibre production needs highlighted. The location the focus of this presentation is positioned centrally to take advantage of what is a growth industries of precision agriculture. The links between both the university and wider community enable students to have access to developments in drone technology for cattle production, joint partnerships with the fruit industry to find the best time for picking to retain sweetness of fruit, and the partnerships with various meat associations with research into best practice transport to enhance marbling of the meat product. STEM resources and activities are able to be provided to students and the wider community to build connections between those in the area.

Key Points:
Provision of real data that has relevance to students in their daily lives will enhance the experiences of the STEM activities. This involves the collaboration between researchers at a local university and community groups and associations such as Fitzroy Water. Providing teachers the connections to the researchers, experts and local associations to support what they do in the classroom. The initiative involves producing a digital STEM book with the research written to meet an audience of Grade 6 to 9. The book will be supported with activities for the classroom.

Keywords: Partnerships, Quality Learning and Teaching
TEACHING AND LEARNING IN MATHEMATICS: CROSS CULTURAL PERSPECTIVES OF TEACHING STRATEGIES THAT SUPPORT LEARNERS

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ABSTRACTS

1. Efforts over the past decade to improve schools’ numeracy performance have placed greater emphasis on students with disability to complete more challenging levels of numeracy. Given these expectations and the continued achievement difficulties students with disability experience, there is a need for special education teachers to have a repertoire of instructional strategies that they can use to assist students. The combination of wide-ranging deficits in foundational numeracy knowledge, experiences and skills and the pressure to increase student performance in numeracy places students with disability at greater risk for failure unless specially designed instruction and resources are provided by their teachers.

There is strong evidence to suggest that teachers (not all) lack sufficient mathematics and numeracy content knowledge and pedagogical content knowledge. Whilst there is a strong commitment from teachers to support students with learning numeracy, unfortunately, their preparation and capacity to teach it is of current concern. Many have poor understanding of teaching and learning for specific content areas, resulting in an overemphasis on procedural and low level skills and limited use to multi-sensory and multi-representational teaching strategies. These strategies are important because they allow flexibility for curriculum implementation across a range of mathematical concepts; provide multiple opportunities for students to develop and learn mathematics where they can represent their thinking in a range of ways. Such ways, visual, auditory, kinaesthetic and tactile learning aids memory and retrieval.

2. Personalised Learning and Students’ Attitudes Towards Mathematics: A Case Study in one 3rd Grade Classroom

A suburban school district in southeastern Connecticut was starting to adopt a personalised learning framework for all students K-12. Research indicates that a personalised learning framework will provide more access to curriculum, greater interest, and deeper thinking for students involved. Prior to the 2017-2018 academic year, a group of sixteen primary-school teachers employed in this public school district were selected to facilitate a personalised math pilot. The pilot group’s work would influence district-wide implementation of a personalised learning framework. The math pilot was guided by a standards-based curriculum. The main focus was on individualised pacing and support of each student’s personal math mastery. Teachers were trained to coach students to make meaningful choices, based on individual strengths, needs, motivations, interests, goals, and experiences. Students were introduced to the research of Jo Boaler
and trained to approach mathematics with a growth mindset. As students began to develop growth mindsets, they began to approach mathematical tasks with a problem-solving perspective. Students began to demonstrate a focus on depth of thinking rather than fast completion times. Technological tools such as DreamBox and STMath were implemented throughout the pilot to differentiate by student need and interest level. Preliminary results of the pilot indicate strong student growth. As a result of this original pilot, phase two implementation will begin at the commencement of the 2018-2019 school year in this school district.

3. Robotics in special education classrooms is attractive because, like most new technology, robots fulfil many criteria for best practice in teaching. Robotics activities are generally student-centred and they encourage independence. Also, the tasks they are associated with are typically goal-orientated, interest driven and are readily differentiated. This latter point is of particular importance in a special educational setting, given the large range of physical, sensory and intellectual abilities typically observed in students. Robots in special education can enhance the educational journey of students, provided that they maintain the interest of the students, and are used within a framework that focuses on “the child’s active role as a constructor and a creator of knowledge”.

The integration of robots in learning allows for making connections to mathematics, in particular, the concept of transformation. Given that this study is being done in a special school, a comparable Australian Curriculum level would be roughly between years foundation to 3, inclusive. Across all these levels, although the precise terminology varies, students need to be able to use and apply directions and carry out and understand simple transformations in relation to themselves. Students with special needs typically find this topic difficult hence, the focus of the study.

4. A Closer Look at Learning Environments and Student Achievement in one STEM Classroom

The opportunity to maximise learning and create meaningful experiences for students requires a reimagining of the STEM-classroom learning environment. Research has shown that transforming traditional classroom learning environments and configurations has had a significant impact on student achievement in mathematics. The traditional classroom environment no longer supports academic achievement in a digitally-globalised classroom. To ensure a school’s commitment to project-based, collaborative, and cooperative learning in the STEM subjects, the classroom environment and instructional leaders must adapt. One classroom teacher in a suburban southeastern Connecticut public school district experimented with her classroom learning environment. Gaining and maintaining student engagement is a high value component of any learning environment, so comfortable seating, flexible groupings, and seating choice were provided to all children on a daily basis. Students sat on stools or rolling chairs and at tables of varying heights that could be arranged to accommodate different groupings, collaboration, and discussion. Student ability to stay focused and on task was improved. A
choice in seating also encouraged interaction and participation. Classroom design also increased this teacher’s ability to connect more readily with students and support multiple teaching and learning styles. When teachers are able to circulate freely, they are able to easily engage with students who need assistance. In turn, engagement, personalisation, and student achievement are supported. Classroom design can foster skills needed for work beyond the classroom. Self-directed learning and collaborative problem solving are essential skills needed for success in higher education and the global job force. Positive initial results from this classroom experiment have warranted further study in this Connecticut school district as well as inspired colleagues to follow suit in beginning to transform the classroom learning environments.

**Keywords:** Mathematics, personalise learning, multi-sensory teaching, multi-representational learning, digital technologies
SCHOOL-INDUSTRY-COMMUNITY PARTNERSHIPS IN STEM

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ABSTRACT

In Australia, concerns about levels of conceptual engagement and participation in STEM in education are allied to calls for STEM Education to be more relevant for students and to focus on knowledges and dispositions that will be relevant for rapidly changing work futures. These ideas are represented strongly in a series of seminal reports coming out of the Office of the Chief Scientist in Australia concerning the state of Australian science and policy directions that Australia needs to commit to. In particular, in these writings there is a strong recognition of the importance of STEM thinking and skills for all students, and an advocacy of the need to more authentically represent the ways in which STEM is practiced in contemporary industry and community settings.

Allied to these perspectives there has been increasing interest in school partnerships with community, industry and scientific organisations, and individuals as a way of opening up the school curriculum to STEM professionals and their practices. This is true of a raft of such initiatives in Europe, the US, and in Asia (Marginson, Tytler, Freeman, & Roberts, 2013). There have also been significant partnership programs in Australia (Tytler, Symington & Smith, 2011) and many locally negotiated partnership initiatives that can involve STEM professionals practicing in a variety of ways.

We argue that STEM school-industry-community partnerships offer the potential, not only of injecting contemporary STEM knowledge and practices into the curriculum experience of teachers and students, but also challenging default teaching and learning practices that are frequently criticised for their lack of fidelity to the diverse ways of thinking and working in STEM. They offer the potential to contribute to the significant re-invigoration of teaching and learning in STEM areas that is called for in so many reports (Office of the Chief Scientist, 2012; 2013; 2014; Office of the Queensland Chief Scientist, 2014).

However there is no general agreement, and considerable gaps in our understanding, about how these changes are to occur and what the resulting 21st century STEM education should look like. Many issues about the nature of the curriculum, the role and skills required of teachers, school management, and external relationship management, remain to be resolved. Moreover there are longstanding curriculum structures and traditional emphases that inhibit desired changes (Hackling, Murcia, West, & Anderson, 2013; Osborne, & Dillon, 2008; Tytler, Symington, & Cripps Clark, 2014).

We believe that STEM school-industry-community partnerships should be viewed as a collaboration towards the evolution of STEM education. These collaborations should enable teachers and their leadership to change
practices and develop new understandings of STEM disciplines, their curricula and pedagogies, especially how they relate to each other and to contemporary practices of STEM professionals. They should enable industry and community partners to understand the challenges of school STEM education and the value and rewards of their contributions to it.

In this symposium we present the experience and findings of three national / state government funded initiatives that developed practical and theoretical approaches to partnerships between schools, teachers, teacher educators and contemporary STEM industry, community and research organisations. These initiatives focused on:

1. partnerships between scientists, teacher education students and teacher educators to explore ways of translating contemporary practice into engaging school activities, and to develop resources to support this
2. partnerships between schools, preservice teachers, teacher educators and STEM industry practitioners to develop units of work
3. investigation of partnerships between schools and industry clusters that developed a framework for teacher professional development in STEM partnerships

The three cases presented in this symposium will highlight challenges to and possibilities of STEM school-industry-community partnerships that include: identifying a strong curriculum purpose for STEM school partnerships; the challenge of identifying the ‘what’ in STEM practitioners’ practice that can or should be productively translated into school activities; issues of boundary crossing between STEM industry and school cultures; the factors involved in sustainability and scalability of partnerships; and the importance of brokers or ‘boundary workers’ in facilitating interactions between teachers, schools, and STEM industry.

Experience shows that this major challenge requires teachers and industry representatives to cross boundaries into unfamiliar domains. Without careful navigation of this boundary crossing, the partnerships will likely fail. Successful partnerships occur because key facilitators or brokers invest considerable energy, intellectual capital and time in planning, liaising and communicating with stakeholders. Engagement of such facilitators is therefore, in our view, an essential part of STEM school-industry-community partnerships and forms a key element in our proposed framework.

**Keywords:** STEM Education, Partnerships
EXAMINING PRE-SERVICE STEM TEACHER REFLECTIONS USING A NON-JUDGEMENTAL AND AFFECT-BASED CRITICAL MOVEMENT PROTOCOL

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ABSTRACT

An examination of critical moments in the STEM classroom is a useful way for pre-service teachers to understand the experience of teaching. This symposium examines the development and trialling of variations of a novel protocol that enables pre-service mathematics and science teachers to reflect on their teaching performance using critical moments based on affect. The emotions experienced in these moments were examined using self and group reflection, considering the thoughts and actions occurring immediately prior to, or during those moments. This protocol was developed in response to the uncertainty in the external determination of, and lack of reliability and validity in evaluation of teaching performance through classroom observation. The affect-based protocol developed, therefore, removes external judgement, relying instead on a pre-service teacher’s self-determination along with guided peer reflection. This symposium presents an introduction to the reflection protocol and discussion papers for four case studies that report on trialled variations of this reflection process in a range of programs and delivery modes in four regional Australian universities.

Keywords: Affect-based reflection, initial teacher education, STEM, pre-service teachers, critical moments
MISSION TO MARS: INTEGRATED STEM LEARNING THROUGH DRONES, ROBOTS AND CODING

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ABSTRACT

This innovative showcase focuses on the integration of STEM learning domains within a complex, student-centred unit of study, research and creation. This showcase will present an argument for an integrated approach to STEM learning and teaching in schools. It will begin with a brief examination of the nature of integrated STEM learning and will be supported by literature. The showcase will then engage participants in a sequence of four hands-on activities, each of which will present a STEM learning concept and experience connected to the topic of the exploration of Mars. The three authors of this showcase will move between the activities to provide small-group support and guidance. The showcase will end with a review of concepts developed and questions raised. Participants will be encouraged to take photos and video of their learning experiences that will offer stimulus for ongoing learning back in their education settings.

Participants will enhance their knowledge and skills of problem-based learning within an integrated STEM learning sequence. They will also gain an experience of integrated STEM learning from a student’s perspective while developing their own professional knowledge. This 90-minute innovative showcase will see participants engaged in hands-on practical learning and discovery with drones, robots and coding, and supported by expert leaders within the field.

Keywords: STEM, learning, robotics, coding, integrated STEM
KITCHEN CHEMISTRY - TAKING THE COOKBOOK OUT OF THE UNDERGRADUATE LABORATORY EXPERIENCE

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ABSTRACT

Lab based learning experiences provide rich opportunities for students to practise science in an authentic context, developing and evidencing core discipline-specific graduate capabilities. Despite the inherent value, laboratory based practicals are expensive to resource (materials, staff time, laboratory space, etc), and therefore are typically constrained and prescriptive. Given these limitations, how do we prioritise and safeguard skill based learning to prepare students for careers in STEM disciplines?

This showcase aims to highlight a novel solution to facilitate the transition from first year STEM undergraduate to skilled STEM professional. “Kitchen Chemistry” provides a ‘low-stakes’ lab-based learning environment where the emphasis is on developing technical proficiency, problem solving skills and scientific literacy, without academic consequence.

Through immersion in a typical undergraduate laboratory practical, participants will have the opportunity to reflect on the value of low-stakes skill-based learning to enhance problem-solving and creative thinking competencies, resilience and building scientific ‘identity’. Further, we encourage participation from both secondary and tertiary STEM educators at the showcase; identifying and understanding the skill-based learning curve for first year STEM undergraduates will help both parties of educators implement strategies to ensure a smooth transition from high school to university.

Keywords: Active learning, graduate capabilities, laboratory skills, professional identity
ENGINEERING EDUCATION IN THE PRIMARY SCHOOL

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ABSTRACT

This Innovative Showcase will display an engineering education program that has been implemented over several years in Brisbane state and independent primary schools. The Showcase will feature teachers and students from two schools who have been involved in the program, together with the researchers who designed it. Engineering is a neglected component of STEM education, especially in the primary school. Yet research has shown the capabilities of young students to engage in engineering experiences and to independently solve engineering-based problems (English & Moore, 2018; English & King, 2017). This Showcase will begin with the authors providing background to the study, which was the second of two projects supported by Australian Research Council Linkage grants together with support from the Queensland Department of Transport and Main Roads. Next, the teachers will describe how they have continued with the project beyond its funded life. They will report on some of the activities and indicate how they have incorporated the program within their school curriculum. Students’ achievements will be showcased, with those who have been involved in the program describing their experiences and presenting examples of artefacts they have created. The Showcase will demonstrate how engineering education can be integrated within the primary curriculum and enhance students’ learning across the STEM disciplines, as well as foster positive attitudes towards STEM. The audience will be invited to contribute to the Showcase through interacting with the participants in questioning, discussing, and sharing ideas. The audience will gain insights into innovative approaches to integrating engineering within primary STEM education.

Keywords: Engineering Education, Design Processes, Primary Grades, STEM integration
ABSTRACT

QUT’s STEM School Engagement Strategy creates real-world STEM opportunities for school students and has been running for over five years in its world class $230 million Science and Engineering Centre (SEC). Home to The Cube, one of the world’s largest digital interactive displays, and dedicated school education space, the inception of the SEC saw a significant investment from the University. The result was QUT’s STEM pipeline for the next generation of STEM leaders.

This Innovative Showcase will take participants on a journey of the strategy’s successes, from conception through to future evolutions, as an exemplar of implementation for their own schools and institutions. The showcase will demonstrate how it interprets relevance from National STEM policy and University priorities to implement a real-world interdisciplinary approach to student engagement; how it garners academic and undergraduate buy-in; how it brokers meaningful relationships between schools, universities and industry; the data evaluation of impact and return on investment and the infrastructure, funding and executive support that underpins its success.

Participants will experience a hands-on example of a QUT STEM school project that integrates cutting-edge QUT research with undergraduate mentorship, teacher participation and curriculum-mapped student resources. To finish, participants will have the opportunity to ask questions of a panel of key stakeholders – from past student participants, teachers, key academics and industry partners who have been instrumental in establishing the success of this program. They will share their personal anecdotal evidence of this QUT approach to creating meaningful STEM opportunities for school students.

Keywords: STEM education, QUT STEM, STEM strategy, school outreach, exemplar program, high school engagement, curriculum-mapped experiences, teacher professional learning
CO-DESIGN OF CURRICULUM AS PROFESSIONAL DEVELOPMENT: A HANDS-ON EXPERIENCE

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ABSTRACT

The aim of this innovative showcase is to present the case for co-designing the curriculum as professional development through a hands-on, practical experience suited to both teachers and teacher educators. Our research team has spent the past year working with teachers and schools to develop term-long units of study for the high school ACARA Digital Technologies curriculum. The preliminary results show that the approach has been successful at both developing teacher capacity and leading to quality student work. This two-hour participatory showcase will include an introduction on the theme of “why co-design?” and exercises that incorporate design thinking processes, tools, and mindsets in using technology to support collaborative curriculum development. Participants should bring a device and an idea for a STEM context in which they might want to develop a plan for a term of teaching (e.g., school context, year level, and subject area). The showcase concludes with some examples from our work using this approach, including feedback from teachers, examples of student work, and ideas for how the approach could be adopted on a broad scale. We make the argument that funds otherwise used to develop centralised “resource repositories” and/or “drive-by” professional development workshops might be better utilised supporting the development of teacher capabilities through co-design – particularly in relation to the ability to teach for student development of 21st Century skills.

Keywords: Co-design, digital technologies, design thinking, curriculum, professional learning, professional development, 21st Century Skills
ABSTRACT 1

The epistemological framing of the curriculum for teacher education based on experience with STEM workplaces.

Premnadh. M. Kurup, Michael Brown, Xia Li & Greg Powell

There is a mismatch between the organisation of knowledge in school curricula and teacher education with emerging and more complex conceptualisations of integrated knowledge that are currently being used in adaptive workplaces. At the forefront of these more complex conceptualisations of integrated knowledge is STEM (Edwards, Perkins, Pearce & Hong 2015). Yet it is suggested that STEM may be more usefully thought about as the development of epistemic fluency and what is being referred to also as actionable knowledge and knowledgeable action (Markauskaite & Goodyear 2017). This research aims to explore to what extent there are similarities and differences between current constructions of STEM and the need for epistemic fluency within authentic workplace settings. This research is based on the visits of an interdisciplinary team of academics to STEM related workplaces to negotiate and build educative alliances between university based academic staff and three STEM orientated workplaces; analyse the basic work organisation and work practices in one of these workplace settings with a view to identifying STEM and/or the epistemic framing of preservice teacher's capacity to teach STEM curricula (in terms of actionable knowledge and knowledgeable action).

The research observations are based on these visits and the notion that teachers need to build capacity to understand and teach STEM and/or other complex integrated knowledge constructions in their future teaching. This study could provide an insight to clearer understandings, practices and may generate an alternative to guide the curriculum for professional
education in general and for teachers more specifically. This study has the potential to interrupt current understandings of STEM thereby seeking closer alignment between the preparation of young people for work in the future through school curricula and productive knowledges within workplaces.

ABSTRACT 2

Dr. Leila Afshari

Increased focus on the innovation-based and technologically advanced future in Australia has recently highlighted the importance of diversity in Australian workforce and particularly in engineering and technology-related jobs. Diversity was found to be essential to developing creative engineering solutions in response to complex global issues. Despite the highlighted importance of diversity, women remain dramatically underrepresented generally, in Science, Technology, Engineering, and Mathematics (STEM) related professions. Less than 5% of women selected ‘Engineering and related technologies’ field of study in 2011 (Australian Bureau of Statistics, 2012). Previous research in women’s under-representation have concluded that women’ identities play crucial role in women’s persistence in STEM education and professions (Cadaret et al., 2017; Robnett & Thoman, 2017; Vincent-Ruz & Schunn, 2017; Godwin et al., 2016, Hardin & Longhurst, 2016; Szelényi et al., 2016). Informed by the findings of previous research, I am seeking to better understand women’s under representation in STEM education and professions by examining the interplay between environmental factors and development of their identities. The ultimate aim of this research is to provide a model which identifies the supportive environmental factors in development of women’s professional identities through their journey from education to professional careers in STEM fields.

ABSTRACT 3

Matthew Grayland

The La Trobe University has a proud history focused on STEM engagement with high school students throughout Melbourne and regional Victoria, with a particular focus on low SES schools. This has seen La Trobe University staff presenting to schools in Mildura in the far North West of Victoria, to Sale, in the far East of the state. From 2012 to 2016 the outreach program engaged with approximately 1000 students a year. Our STEM sessions are designed to engage students and provide an exciting learning environment, with a hands on approach. These include design and testing of a cars crumple zone, and the building of an economic bridge.

In addition to real world scenarios, our outreach program aims to introduce students to modern technology and the future direction of the engineering profession with a focus on robotics, 3D printing and coding. A recent addition to our outreach work is a professional learning program for high school teachers, to providing a better understanding of the
engineering profession and to provide training in 3D printing and Arduino programming, which can be used for teaching in the classroom.

ABSTRACT 4
Madeline Toner

Over the years, Francesca has developed relationships across the University and has used these to build the Outreach program. The Outreach program, while aimed at high school students, also has an internal professional development aspect in that many of the demonstrators are Honours, Masters or PhD students. Some of these people then go on to be University academics and present in and develop workshops for the Outreach program.

In terms of professional development for teachers, Outreach runs STEM Professional Learning Programs not just in Engineering, but also in Biology (microscopy), Chemistry, Maths, Physics (electricity and magnetism) and Psychology.

ABSTRACT 5
Dr. Adnan Syed Muhammad

The STEM/STEAM research at La Trobe University has a multidisciplinary focus that has researchers from the School of Education, the School of Business and the School of Engineering and Mathematical Sciences working from their own disciplinary perspective. The Industry Research Partnerships Team at La Trobe University provides linking opportunities to researchers across the university working in similar areas to work collaboratively and help them identify industry partners for impactful research. In the case of STEM/STEAM research, meetings of researchers from three different schools were organised to discuss opportunities and as a result a symposium is being organised to further explore the idea. We believe that the STEM/STEAM research group at La Trobe University will provide a platform to share ideas to advance research in this area and will offer research based solutions to its industry partners.

ABSTRACT 6
Engaging High School Students and Teachers in STEM Disciplines
Francesca Calati

“In a knowledge-led economy we want people with strong STEM backgrounds designing cities, planning infrastructure, sitting on corporate boards and protecting our industries from every risk from climate change to cyber attack – just like every other nation that has made the choice to excel in these fields” (Australia’s Chief Scientist, Dr Alan Finkel, in Just Quietly, The Weekend Australian, August 2016).

It is a conundrum of our times that as scientific and technological advances accelerate, the capacity to produce the scientists, technicians and engineers to meet demand fails to keep pace. Global scientific literacy has
never been more imperative for human health and well-being, but the pipeline for delivering this literacy seems blocked: STEM studies in our schools have stagnated, young people are opting out. The solution lies unequivocally in the career choices of the young men and women in our classrooms, many of whom will soon need jobs on global frontiers not yet imagined. It is our role as educators to prepare them for this.

At La Trobe University Science Outreach, we cultivate the pipeline – mentoring and inspiring talented young high school students to take up the challenges, engage with our scientists, confront the issues of our times, and discover for themselves the global context in which the disciplines of science, engineering, mathematics and information technologies continue to evolve. Our Outreach workshops support Government initiatives to upskill students in STEM, and help high school teachers in guiding their journey. All workshops are aligned to the Victorian & National Curriculum. We provide on-campus opportunities that reinforce science learning and teaching, empowering both students and teachers to raise the bar. Each year approximately 15,000 students from metro and regional schools in Victoria participate in excess of 40 STEM practical workshops which are innovative, challenging, fun, interdisciplinary and flexible.

The Outreach Program, while aimed at high school students, also has a Professional Learning Program to build teacher capacity in STEM. For details of the program https://www.latrobe.edu.au/outreach/she
TACTILE TECHNOLOGIES ARE BONDING WITH STEM

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ABSTRACT

Digital Technologies and robotics provide our teachers with resources and kick-starter learning activities through a variety of STEM entry points in the classroom. These developmentally appropriate Physical Programming learning environments are tactile and tangible and enable even our early years students to harness their imagination while employing fine motor and thinking skills of the highest order. Computational, abstract and design thinking are needed by all ages to solve problems when working systematically with robotic resources that require creativity through the curriculum related STEM challenges. As students develop solutions, select materials, build, test and evaluate their own digital prototypes, they broadly connect with science, maths and engineering while working specifically with - geometry, drawing, mapping, mechanics, electronics, the language of computer science and the programming of input and output devices - in developmentally appropriate ways.

This showcase will highlight the support provided by The Commonwealth Department of Education and Training and the CSER MOOCS to enable all Australian teachers access to participatory training and the latest Digital Technologies activities and equipment available in the classroom.

With the use of Digital Technologies aligned to the Australian Technologies Curriculum, we can see how students can program and learn the language of technology with smart playful learning opportunities that connect holistically within the REAL STEM environment.

Participants will keep it REAL with relevant, engaging, authentic learning as they

- workshop the equipment
- use traditional and new generation resources
- discover and experiment, and
- link learning across subjects and disciplines.

Keywords: Tactile, tangible, digital, participatory
INNOVATIVE TECHNOLOGY USE IN STEM TEACHER EDUCATION

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ABSTRACT

University of British Columbia (UBC) Teacher Education Program is one of the leaders in Canadian teacher education. We educate nearly hundreds elementary and secondary Teacher-Candidates (TCs) annually who will become teachers in Canada and abroad. Many of these TCs are STEM teachers. For the last decade, we have been investigating different ways of incorporating modern technologies in STEM teacher education and the effect of research-informed technology-enhanced pedagogies on the growth of their pedagogical knowledge and attitudes about STEM learning. We also have studied how incorporating technology in teacher education can support the development of TCs’ deliberate pedagogical thinking with technology that aims at increasing student active engagement in STEM. In this workshop we will demonstrate five different innovative ways of incorporating educational technologies in STEM teacher education. Our goal is to promote the growth of TCs’ Technological Pedagogical and Content Knowledge, their creativity, and their ability to use technology deliberately with the purpose of increasing student engagement with STEM. Specifically, we will show why, when, and how we have been using digital sensors (Logger Pro), Electronic Response Systems (clickers), PeerWise online system, computer simulations and modelling software (e.g., PhET, GeoGebra), and Video Annotation software (Collaborative Learning Annotation System) to help TCs experience active STEM learning in their methods course and prepare them for a using these tools during their school practicum. We will discuss the pros and cons of each one of these technology-enhanced pedagogies and invite workshop participants to experience them in practice both as learners and as teachers.

Keywords: Collaborative Learning Annotation System, Deliberate Pedagogical Thinking with Technology, Educational technology, Logger Pro, PeerWise, PCK, STEM Teacher education, TPACK.
This Innovative Showcase will take you on an inspiring journey into the rapid success of a State Schools Robotics Club. The team will recall the humble beginnings of a small club, to a sustainable gender balanced program that has expanded across the P-12 Curriculum and flourished on a National and International world stage. This excellence in STEM initiative was lead through robotics and built into the club, junior and secondary electives and senior engineering courses. They will detail how they addressed and increased female engagement in STEM based senior subjects and extra-curricular activities to build our future female engineers. Identifying the strategies of how to attract girls into robotics through culture and brand development for a sustainable and equitable ratio in class, competition and university uptake. The team will conclude with an interactive robotic experience, sharing and teaching some basic robotics skills that aim to empower and educate participants to start their own Journey.

Keywords: Chancellor State College Robotics Club, interactive robotic experience, robotics within the curriculum, excellence in STEM initiative, increased female engagement in STEM, future Female Engineers, roboGEMS (Girls in Engineering, Maths and Science)
ABSTRACT

In the 2018 Optimising STEM Industry-School Partnerships report Dr Alan Finkel stated it is his belief that “Industry-school partnerships have important, even life-changing impacts” (Education Council, 2018). Industry participation in STEM education can provide the opportunity for curriculum content to be aligned to workforce practices, often resulting in students having higher engagement in the subject and seeing the relevance of classroom learning (DEEWR, 2013) (Australian Government, 2018). Furthermore, industry-school collaborations can increase student and teacher knowledge and awareness of STEM career pathways, and raise the skills and aspirations of the future workforce. However, many challenges exist for both schools and industry in accessing and creating meaningful and long lasting STEM education collaboration activities.

Over the past five years, with a focus on students from low socio-economic status backgrounds, Aboriginal and Torres Strait Islander students, and students from Australia’s remote and regional areas, the Beacon Foundation (Beacon) has investigated the role technology can play in ensuring there are no barriers to accessing industry-school partnerships, as well as their role as an external facilitator, or broker, in maximising student outcomes associated with industry-school collaborations in STEM education.

The presentation will focus on demonstrating Beacon’s fresh and innovative approach to industry-school partnerships which is accessible to all. Participants will have the opportunity to participate and interact with industry and school participants, as well as partake in a conversation regarding effective industry-school partnerships with industry, education and student representation.

Over the one hour presentation, participants will:

- Discover that industry-school collaboration can be accessible to all, and become part of everyday STEM education classroom delivery, even in remote and regional areas.
- Learn about the benefits of facilitated, or brokered, industry-school partnerships, and its scaling potential.
- Participate in a live STEM education industry-school collaboration, and stakeholder conversation.

Keywords: STEM, STEM education, technology, collaboration, industry-school partnerships, disadvantaged communities, low socio economic background, facilitation, broker, remote and regional areas, scalable.
DEVELOPING SEQUENTIAL THINKING IN PREP STUDENTS

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ABSTRACT

In an increasingly digital world much of the debate has focussed on how we prepare students for the future. When our current students are entering the work force many of the jobs that may be available have not yet been developed. This is due to technological advances and why the curriculum area of Digital Technology plays such a profound role in preparing our students for the future. In this current teaching climate where Digital Technologies are a focus of the curriculum, activities for Prep students are often glossed over and the focus is on activities and computational thinking for older students. The assumption of this paper is that Sequential Thinking is a precursor to Computational Thinking and Algorithms. The development of Sequential Thinking can be done in Prep with a wide variety of activities and with minimal cost to schools. This can also lead into a greater understanding of computational thinking and lead to greater success for older students in Digital Technologies. The aim of this presentation is to demonstrate activities that can be easily implemented in a wide variety of contexts. Participants will be encouraged to be creative and to innovate on ideas to integrate into the Digital Technologies curriculum. Participants will be able to see activities that develop sequential thinking are easily integrated into other curriculum areas, activities can be time and cost effective with little organisation required and provide a model of practice that has been implemented into a school.

Keywords: Prep students, Sequential Thinking, Digital Technologies
ENGAGING HIGH SCHOOL STUDENTS WITH GAMIFIED MATHS APPS

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ABSTRACT

Engaging high school students with mathematics is difficult. Numerous studies have shown that student performance increases when engagement increases. This makes improving student engagement with mathematics both an important and challenging problem to solve. Gamification, the use of game mechanics in a non-game context, is progressively being used as a strategy to improve student engagement, due to its ability to motivate students. Math Mate, an education technology start-up is developing gamified learning apps for high school students that encourage play, exploration, and interactivity when learning algebra. In this showcase I will: demo a novel interface for mathematics that lets students play with expressions and solve problems without the need for pen and paper, outline the key design choices made to improve student engagement, report our results and learnings from working with schools in 2018, and invite you to use the apps to solve problems and engage in a friendly competition. By the end of the showcase, you should be able to: identify and assess the value propositions of gamified mathematics software, solve problems using a new mathematics interface, and leave with a smile after engaging in some friendly competition.

Keywords: Gamification, high school mathematics education, student engagement, start-up, play
Workshop Abstracts

WATER IN THE 21ST CENTURY: EXPERIENCING MODULES FOR STUDENT-CENTRED STEM PRACTICES FROM THE ISME PROJECT (STELR)

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ABSTRACT

Despite arguments for the implementation of student-centred learning programs in the classroom-learning environment, it is arguable whether a widespread student-centred approach to teaching and learning has been adequately adopted. This workshop shows education practitioners how to implement units in the module, Water in the 21st Century, developed from collaboration between Southern Cross University and the Australian Academy of Technology and Engineering (ATSE) as part of the Inspiring Science & Mathematics Education (iSME) project. This module situates the teacher as the facilitator and students are provided with authentic and meaningful opportunities to engage in conceptual development in STEM literacy through problem-based learning activities. Moreover, there is increased capacity to introduce students to an actual student-centred learning environment through this approach.

Water in the 21st Century has four units designed to address critical issues in understanding the role of water in the modern world. The units have been trialled successfully in Australia, Indonesia and Nepal, with delivery through a web-based platform (ATSE’s STELR website) and a dedicated materials kit.

- Unit 1: Water World–planetary water and availability
- Unit 2: Just add Water–economy and equity
- Unit 3: Water for Life–human biology and ecosystems
- Unit 4: Water Farming–water quality and water recovery

The workshop will provide an opportunity to look at two of the challenges presented within Unit 4:

- Challenge 10–Invisible Water
- Challenge 11–What if you ran out of fresh drinking water?.

Booklets and equipment will be provided, and online access of participants will be beneficial.

Keywords: STEM practices; student-centred learning; water; Australian Curriculum Science; technology-enhanced learning
PROJECT DESIGN FOR THE STEM CLASSROOM: A VR CASE STUDY

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ABSTRACT

In this workshop, educators will have the opportunity to develop and enhance STEM projects for their classrooms using a STEM Project Design Process designed and implemented by a leading STEM Education hub. Curriculum designers from STEM education and outreach centres will highlight two STEM Projects (aimed at Years 6 - 10) that effectively incorporate Virtual Reality into student-centred class activities while aligning with curriculum standards. These will be shared using this common design process as the context and participants will participate in a sample experience from each existing project. Participants can expect to create and/or refine STEM projects for their own classes during this interactive workshop. Using presenter examples and the STEM Project Design template, participants will work in small groups with like-minded educators, collaboratively building their innovative project ideas. The experienced workshop leaders will provide feedback and guidance for educators during this process. Workshop leaders incorporate interactive design-process activities, provide participants an opportunity to engage in an effective class project using VR, and share guidance as participants take time to work through the design process for their own projects. This workshop will give educators: the template to design their new STEM projects, the exposure to a new mode of content delivery in VR, and the time focus on building their own creative projects.

Keywords: Virtual Reality, Secondary, Project Design, Curriculum Development
WHY GO ROUND IN CIRCLES IF YOU CAN CUT STRAIGHT ACROSS? YUMI DEADLY MATHS BEATS ROTE LEARNING!

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ABSTRACT

The basis of this workshop is to demonstrate that kinaesthetic activity and discussion foster understanding. To this end, participants will be encouraged to work together hands on in developing the intuitive discovery of the relationship of circumference of a circle to its diameter. This will be generalised so that a symbolic form of the outcome can be developed. Discussion will focus on how this type of cooperative and inquiry learning is an effective way of teaching as it enhances sense of belonging and working together to achieve an outcome. Inquiry learning needs a context that is familiar to students, and suitable materials to support their understanding. Since personal involvement and cooperative inquiry aid creation and retention of visual memory, a wider than usual range of students can relate to the development of a formula that has universal application in STEM fields.

Keywords: Connections, cooperative learning, generalising, inquiry, justifying, mathematical reasoning, measurement, kinaesthetic learning
ABSTRACT

Rewarding risk-taking effectively and efficaciously continues to challenge participants in STEM learning opportunities. This presentation is concerned with showcasing the Victorian Certificate of Education Systems Engineering Study Design and its innovative assessment programme that rewards participants for ‘failure’ as they conceptualise, investigate and develop intentions towards solutions, then carry out plans and evaluate any results. This workshop will present open-source, accessible applications that may be harnessed to create interactive digital portfolios that learning participants in STEM may use to narrate their creative journey, inclusive of successes and failures, as they seek to provide evidence of achievement in their learning. We will unpack a collection of real digital portfolios to discover how learners valued getting things wrong on their way to getting things right. Authentic reward for risk-taking is foregrounded in this workshop, for learning environments that explore systems approaches to developing solutions to real problems.

Keywords: Digital portfolio, Systems Engineering, Risk-taking
ABSTRACT

There is increasing pressure for early childhood educators to be engaged in reflective practice around the effective implementation of appropriate inquiry-based STEM pedagogies (DEEWR, 2009). This 60-minute workshop explores the practical application of an inquiry-based pedagogical framework in STEM appropriate for teaching and learning in early childhood education settings. The aim of the workshop is to critically engage educators to reframe how they currently implement STEM experiences for young learners. Participants will have the opportunity to apply, discuss and evaluate an inquiry framework that has been designed specifically for application in early childhood settings. The workshop will provide opportunities for educators to engage in professional conversations and experiences that cover the following three areas:

• Where are we at? - challenges and successes relating to current STEM practices.
• What can we try? - experience a specific early childhood STEM inquiry framework in action.
• What do you think? – critique, adapt and future planning.

Keywords: Early Childhood Education, Pedagogy, STEM
A MODEL FOR STEM: CREATING A PET CAR ALARM

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ABSTRACT

This workshop will both propose and demonstrate a model for implementing a STEM event in schools with a cohort of students over a two-day period. The notion of ‘master classes’ will be explored both through discussion and practise as a basis for engagement in the task. This presentation is important as it offers an alternate model of implementing STEM in schools where there is limited availability of time for projects in the middle school, and can be completed without drawing time from specific curriculum areas.

This presentation has a practical component. Participants will engage in a shortened version of the project through sample investigations in ‘mini master classes’ which will be directed by the presenters and workshop notes, that can be used as a foundation to mimic the project in their own schools. These ‘mini master classes’ will cover the science experiments for the task, mathematical modelling of the data, material analysis and the design process, and the coding to activate the Pet Car Alarm. The activities are designed to be understood thoroughly at a Year 8 level, so limited experience in any of the fields covered is assumed.

This model of engaging students in STEM through the use of master classes offers a valuable contribution to the implementation of STEM in schools as it enables rich learning, transfer of ideas across the bounds of curriculum and the sense of success through the completion of the project in a short span of time.

Keywords: Model, master classes, engagement
A STUDENT-CENTRED, PROJECT-BASED APPROACH TO STE(A)M

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ABSTRACT

Reason for this presentation: There are many STE(A)M projects offered to teachers and students, but they are not always flexible, economical, driven by curriculum or founded on project-based learning. Combining classroom experience and extensive market research, the presenters have created a new teaching and learning program for implementing authentic and engaging STE(A)M activities in schools. Aim(s): The aim of this session is to provide participants with hands on experience with engaging, rich, project-based STE(A)M activities. Participation: Attendees at the session will engage with two (2) STE(A)M activities. Each of these activities takes project-based, problem-solving approach to STE(A)M teaching and learning. Participants will take on the ‘role’ of student and complete meaningful and relevant STE(A)M activities that can be used in across the curriculum or used with STE(A)M clubs or STE(A)M weeks.
AUTONOMOUS VEHICLES – DRIVING MATHEMATICAL THINKING

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ABSTRACT

Five years ago autonomous driving was possible, now it appears inevitable. Companies like Tesla and Google have disrupted this landscape creating an industry that is expected to contribute more than $10 trillion to the global economy. The horseless carriage is morphing into the driverless car. The 2004 DARPA Challenge involved building an autonomous vehicle that could track a course across the Mojave Desert. Entrants modified vehicles, wrote their own code then let their creations loose in a semi controlled and monitored environment. While most vehicles crashed within sight of the starting line, the event engaged the minds of engineers, mathematicians, computer scientists and even the backyard enthusiasts and signalled to the world that autonomous vehicles would no longer be a throw away scene in a science fiction movie.

What does all of this mean for the students of today? Aside from the pending changes to driving and driving conditions in the near future, autonomous vehicles represent an amazing opportunity to contextualise a range of mathematical problems, engage in purposeful coding, thinking and reasoning. The TI-Innovator Rover is a purpose built classroom resource that connects to the student’s TI-Nspire™ or TI-84PlusCE™ handheld calculator, therefore providing access to a range of mathematical functions and operations that can help drive the robotic vehicle.

With access to commands such as “Go To X,Y”, the Rover is capable of bringing graphs to life and making the Cartesian plane somewhat more tangible. In addition to a range of commands that drive the vehicle, numerous sensors can be connected, making Rover as much a part of the science classroom as it is mathematics; this is one of the challenges facing STEM implementation.

This paper provides examples of activities that are accessible to students just starting to learn about the Cartesian plane through to those studying Euler’s approximation for solving differential equations. In addition to a selection of activities the IBM 7094 in the corner of the room will also be discussed. How do we upskill, resource and re-educate a depleted workforce that has been primarily trained to work within a single discipline? If the disciplines within the STEM acronym continue to be taught in isolation, then it is simply CURRICULUM, The Australian Curriculum documentation states: “STEM is addressed in the Australian Curriculum through the learning areas of Science, Technologies and Mathematics, and through general capabilities, particularly Numeracy, Information and Communication Technology (ICT) capability, and Critical and Creative Thinking”. The absence of a united STEM domain reduces the responsibility and ownership of any individual or team within the school to ensure the relevant content is covered in any significant or
cohesive manner. The activities referenced in this paper, in part, reflect this continued compartmentalised approach focusing mainly on the mathematical content. It has been the Author’s experience that activities that are truly multidisciplinary are much less likely to be included within the schools practiced curriculum.
ABSTRACT

Madeup is a language for making things up, in both a creative and geometric sense. It allows learners to create 3D structures by writing algorithms that move and turn through space using mathematical operations, loops, conditional statements, and many other common programming constructs. The path that is traced by the program is then interpreted as a cross section or skeletal axis and is solidified to form a solid object. The output is not a number or a picture, but a 3D model that can be interacted with, embedded in an immersive environment, and even printed on a 3D printer. In this interactive hands-on workshop, participants will learn to build models using Madeup and gain skills and resources they can use to combine making with computer science and mathematics in their classrooms and makerspaces.

Keywords: Computational making, 3D modelling, Logo
ABSTRACT

The newly implemented Digital Technologies curriculum gives Australian schools the opportunity to rethink their pedagogical approach to STEM integration and to explicitly incorporate authentic coding activities into STEM subjects. This workshop aims to present a practical and accessible pedagogical model, STEM Coding, for the integration of secondary school Mathematics, Science and Digital Technologies through innovative and stimulating coding activities that go above and beyond conventional digital widgets and interactives. It prompts participants to explore possible curriculum connections amongst STEM subjects from the perspective of coding. Participants will actively engage in the development and implementation of four separate, yet interrelated, coding activities that illustrate basic to advanced levels of STEM integration. All four exemplary coding activities can be further modified or expanded by participants later on to create their own units of work to suit individual school settings. Although many software platforms and development tools are suitable for the implementation of STEM Coding, p5.js supported by its web-based editor constitutes the most accessible option for secondary school students with little to no experience in general-purpose, text-based programming languages, and will thus be thoroughly introduced to participants. All workshop materials and additional resources can be freely accessed at https://sites.google.com/view/stemcoding.

Keywords: Coding, STEM Integration, Australian Curriculum, Secondary School
LEADERSHIP TEAM DRIVEN SCHOOL SYSTEMIC CHANGE. THE CREATION OF STEM FOCUSED SCHOOLS

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ABSTRACT

The growth in Science, Technology, Engineering and Math (STEM) schools and programs has outpaced national and state level policy guiding schools towards a common set of STEM teaching practices and learning outcomes. School and district leaders who are often tasked with leading such processes may lack expertise and resources to implement high-quality STEM plans school-wide. This workshop will focus on the need to develop STEM-specific leadership capacity at the K-8 level and explore professional development strategies as means to address this need. The presenters, who each developed leadership-focused STEM professional development programs through their Universities, will summarize the key characteristics of their programs and share preliminary evaluation findings. The STEM-leadership professional development programs (implemented by University A and B) serve different populations of educators in very different contexts but with similar strategies and key programmatic features. The workshop presenters will 1) discuss the key features of their STEM-leadership programs, 2) share lessons learned from each of the program evaluations and 3) engage participants in sample STEM-focused strategic planning exercises. The workshop serves as an opportunity for participants to consider and discuss the value of leadership-focused professional development as a means to support strategic planning for STEM education and ultimately increase student access to quality STEM education opportunities school-wide.

Keywords: STEM-Schools, Professional Development, Leadership, Evaluation, K-8, Strategic Planning, systemic change
CORALWATCH: REAL-LIFE CORAL REEF DATA AS A RESOURCE IN YOUR CLASSROOM

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ABSTRACT

In the absence of a specific “STEM” curriculum, many educators seek resources that seamlessly integrate these four disciplines. CoralWatch provides educators with a well-resourced, flexible vehicle to deliver STEM education in the classroom. Modelling classroom practice, workshop participants will:

• Experience the reef through immersive virtual reality
• Collect and analyse coral reef data
• Collaboratively develop strategies to enact change in reef conservation.

Throughout the workshop, participants will clearly identify the links to Science, Technology, Engineering and Mathematics that can be made for a range of educational contexts spanning year 1 to year 12. Specific CoralWatch year level resources aligned with the Australian curriculum will be presented during the workshop including opportunities to explore the cross curricular priorities of sustainability and engagement with Asia. By using samples of student work as evidence of learning, participants will see how CoralWatch promotes student engagement, improves students’ STEM skills and in the process develops teacher capacity to deliver STEM in the classroom.

Keywords: CoralWatch, coral reef, data investigation, data analysis, science, mathematics, creative thinking, communication, citizen science
ABSTRACT

The popularity of robotics in education has accelerated in the past 5 years. The LEGO Education Robotic system bring abstract concepts to life in a fun, hands-on approach. LEGO bricks turn ideas into physical models that can be touched, described, and manipulated and help students develop the essential skills they will need in tomorrow’s world. LEGO Education products use both physical and digital creations to build up teamwork, communication abilities and strong collaboration and so making students more independent and self-confident.
DEVELOPING DEEP MATHEMATICAL UNDERSTANDING IN A STEM CONTEXT

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ABSTRACT

The YuMi Deadly Maths pedagogy encourages deep understanding of powerful mathematics through a focus on sequencing, connections and big ideas. There is a concern that these deep understandings are often lost in an integrated STEM context. Research is showing that the vision for integrated STEM is not being realised and has the potential to undermine in-depth student learning. This presentation will encourage participants to experience, hands-on, some common STEM activities incorporating technology to highlight the potential for deeper mathematical investigations. A variety of technologies and some introductory coding opportunities will be used to engage participants in these investigations. The focus will be on what is required to ensure the role of mathematics in STEM activities is such that it allows for deep mathematical understanding, and to recognise when and how to ensure there is mathematical depth.

Keywords: Deep learning, powerful mathematics, integrated STEM curricula
USING MULTI-SENSORY TEACHING STRATEGIES IN SPECIAL EDUCATION
TO DEVELOP MATHS UNDERSTANDING IN STUDENTS WITH MULTIPLE
DISABILITIES

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ABSTRACT

This workshop aims is to illustrate the multisensory mathematics teaching strategies in special education. It introduces an effective pedagogy that utilises manipulatives designed to meet learners’ specific physical and academic needs, emphasising hands-on activities and holistic learning. This pedagogy promotes experiences that are engaging, explorative and suit all learners’ abilities. A major component of this teaching methodology is the concept of full inclusion – namely, all students are encouraged and supported to participate in the experience.

The presenters will demonstrate the effectiveness of teaching mathematics in ways that empower students with diverse learning challenges to develop their mathematical and communicative abilities. This multisensory pedagogical approach maximises student engagement and learning whilst outfitting them for lifelong learning and making STEM more accessible to special needs students and teachers.

In this workshop, participants will actively engage in a simulated learning environment. They will take part in multisensory mathematical learning experiences utilising developmentally appropriate resources to explore the concept of area. Presenters will provide guidance on the implementation and teaching strategies that form the basis of the pedagogy.

This experience will allow participants to develop an understanding of the effectiveness and ease with which this multisensory pedagogy can be implemented into special education settings.

With its focus on multisensory teaching and hands on investigation, this pedagogy captures special needs students’ attention, caters for their abilities and encourages exploration and discussion. It enables students with multiple disabilities to participate in mathematics learning experiences in a fully inclusive learning environment.

Keywords: Multisensory, full inclusion, mathematics, teaching strategies, pedagogy, special education, manipulatives, hands-on, learning environment, student engagement
LEARN VECTORS WITH TI INNOVATOR ROVER AND USE THE TI INNOVATOR HUB IN THE PHYSICS CLASSROOM TO IMPROVE CONCEPTUAL UNDERSTANDING

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ABSTRACT

This session will focus on use of TI technology (TI nspire CAS CX, The Innovator hub and TI innovator Rover) to improve conceptual understanding of certain concepts in Physics. The session will have a STEM focus as we will model / simulate Physics activities using coding, graphing and designing practical activities. The TI innovator Rover (A robotic vehicle will be programmed to follow a linear paths with variable parameters). This motion and path will be then be used to do a mathematical and physics analysis of the motion. Using the TI Innovator Rover to understand Vectors and Bearings will be an initial introductory activity.
LEGO EDUCATION: EXPLORING STEM AND MUSIC WITH RUBBER BANDS AND LEGO

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ABSTRACT

This hands-on workshop will present a new way for teachers to introduce students of all ages to the STEM concepts related to musical instrument making. Understanding the propagation and perception of sound are key features of learning standards, from relating noise to vibrating matter in pre-K to understanding frequency, period, and wavelength in high school. This activity is designed for students to explore these concepts at any level of complexity, while engaging them with scientific inquiry and engineering design practices. You will first be introduced to contact microphones, a tool that turns the vibrations of a material into sound, as a way of investigating the transfer of vibrations and more clearly hearing rubber band strings. We will then explore how to control the pitch of a musical string by changing the length, thickness, and tension of rubber bands, designing experiments to isolate each variable. Participants will then design and make a musical instrument out of LEGO bricks and perform for the group. The workshop will finish with a group discussion about designing STEM learning environments to introduce students to content knowledge while engaging with scientific inquiry and engineering design.

Keywords: STEM, LEGO, Sound, pitch
USING THE RELEVANT CONTEXT OF SUSTAINABLE HOUSING TO TEACH STEM SUBJECTS

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ABSTRACT

Sustainable Housing is a multidisciplinary STEM module designed to be taught at year 9 level. It maps into the Physical Sciences strand of the Australian National Science Curriculum and has embedded maths and technology activities. It features a purpose-built equipment kit.

Sustainable Housing aims to increase the numbers studying maths, technology and sciences at senior high school by showing the relevance of STEM subjects to students’ lives, now and in the future.

Participants in this workshop will:

- gain hands-on experience of the equipment pack and data logger
- gather and analyse data
- evaluate support materials
- trial activities
- investigate the effectiveness of building materials and high-tech treatments.

Topics include

- Sustainable house design
- Inquiry-based investigations into building materials (insulation, thermal mass, windows, roofing etc.)
- Transfer of energy by convection, conduction (particle model) and radiation (wave model)
- Daytime astronomy
- Case studies
- Career profiles
- Video profiles of Women in STEM and Entrepreneurship.

The Sustainable Housing module is available as a web-based module or in word and PDF formats.

The Sustainable Housing program was developed by the Australian Academy of Technology and Engineering in collaboration with Wollongong University, Deakin University, Southern Cross University and Charles Darwin University.

Keywords: STEM Secondary, Inquiry-based, Hands-on, Sustainability, Careers
ON THE OAKLEIGH STEAM TRAIN

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ABSTRACT

STEAM presents schools with an opportunity for change. Oakleigh State School has been on a journey to realise this opportunity with a number of key strategic steps taken over the last 6 years involving our whole community of learners. Key has been the adoption of a different lens with which to look at the Australian Curriculum. During this workshop we will discuss the role of design thinking in shaping mindsets, toolsets and skillsets. We will also share practical activities we have used to assist our teachers to engage deeply with the curriculum, identifying connections and lines of inquiry to shape learning. The engagement of our community is an essential part of our work and we will share our successful strategies including our 2018 community event ‘On the Oakleigh STEAM Train’.
ABSTRACT
Programming skills has become an academic subject offering in many schools, including the European Union mandating computer classes for all children (Vlatko, 2015), and a growing national initiative in some countries (e.g., Canada K-12 CanCode program). Job prospects will be best for applicants with knowledge of the most up-to-date programming tools and for those who are proficient in one or more programming languages (Bureau of Labor Statistics 2018). Providing opportunity to learn coding skills for students will be necessary using research supported cognitive learning programs like Microworlds. In order to support student learning, educators will need to be provided workshop training in learning the Logo programming language (code) to create geometric graphics and animation using the MicroworldsEX program. In the STEM workshop attendees will be introduced to the Logo primitive commands and how to program in different contexts. Instruction in creating programs using superprocedures incorporating modular, recursive, and variable Logo subprocedures will be presented. A cognitive monitoring strategy will be introduced to support development and provide a debugging strategy for programming projects. Participants will work individually or in cooperative groups practicing the coding experiences using the MicroworldsEX program on the computer. The workshop facilitator has provided instruction in Logo coding at Iowa State University working with students enrolled in a STEM program. No experience in using the Logo language or MicroworldsEX program is required, but coding with other languages (e.g., Scratch) may be helpful. Participants understanding of basic geometric concepts will support their Microworlds projects.

Keywords: Logo coding, Microworlds projects, programming, problem solving, geometry skills, metacognition and teacher scaffolding
A NON-FORMAL INTEGRATED STEM LEARNING EXPERIENCE THROUGH NATIVE SOLITARY BEE FOR 4TH TO 6TH GRADE STUDENTS

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ABSTRACT
Pollinators are vital to agriculture, and they are also essential for maintaining the structure and function of a wide range of natural communities in North America. However, there is increasing evidence that the health and populations of many pollinator species are in decline. In the U.S., there continues to be a growing interest in educational programs with science, technology, engineering and mathematics (STEM) integration. STEM-integrated programs were developed to help youth apply relevant STEM content and use evidence-based reasoning to solve a real-world problem. The real-world problem that pollinators are facing today is a great context that educators could apply integrated STEM approaches to teach youth relevant STEM contents, and help youth practice evidence-based reasoning. Purdue University faculty and Extension staff co-developed a native solitary bee integrated STEM curriculum that aims to help youth use more evidence-based reasoning. The trained Master Gardener volunteers taught the youth program. The proposed workshop will demonstrate some activities from the integrated STEM through native solitary bee curriculum and discuss what authors had learned from the experiences.

Keywords: Integrated STEM, Afterschool curriculum and program, Evidence-based reasoning, Extension.
ABSTRACT

VRMath 2.0 (VRMath2) is a virtual reality learning environment (VRLE) and an online learning community. It employs the powerful ideas of 3D Logo Microworld and Web 2.0 technologies for integrated learning in STEM (Science, Technology, Engineering and Mathematics). This workshop will involve participants in writing simple codes in Logo programming language to generate their 3D virtual artefacts. Participants will then compose an online blog in VRMath2 community about their creation and share their 3D virtual worlds. Once published online, the 3D virtual worlds can then be viewed using a VR goggle such as Google Cardboard. Through this workshop, participants will experience how coding 3D virtual worlds can be integrated in education and potentially utilise this free online VRMath2 resource in their teaching and learning, and research.

Keywords: Coding, 3D, Virtual Reality, Logo programming, STEM
WE DO COLLABORATION: HOW CAN YOUNG STUDENTS DEVELOP COLLABORATION SKILLS THROUGH STEM AND ROBOTICS?

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ABSTRACT

Collaboration is a critical skill and young students require specific opportunities to practise teamwork, taking turns, listening and negotiating to develop collaborative skills. Learning about robotics is an engaging and motivating opportunity for students to experience teamwork. Through a STEM learning experience, Year 2 students created animated models using LEGO We Do 2.0. The teachers observed the strategies children employed to work effectively to achieve common goals, and their ability to negotiate when creating a shared robotics solution. This poster will present the findings of an action research conducted to consider the potential of Robotics and STEM as opportunities for teaching collaborative skills. By reflecting on data from student surveys and teacher observations, it is hoped that educators will further recognise the potential of STEM and robotics for promoting collaborative skills with young students. This is an opportunity to discuss ideas about the benefits of integrating robotics into a STEM inquiry; to see how robotics challenges can provide scaffolded opportunities for young children to practice teamwork and collaboration skills; and to consider the practicalities around using robotics kits in classrooms.

Keywords: Collaboration, robotics, STEM inquiry, LEGO We Do 2.0
ABSTRACT

An introduction to STEM in Early Childhood allows children to discover and playfully engage with STEM concepts, dispositions and skills, supporting future learning outcomes (Haslip & Gullo, 2017; Newcombe & Frick, 2010; Verdine et al., 2014). Research shows, however, that many Early Childhood educators lack confidence in the STEM fields and feel that they do not have the conceptual skill base to engage children in authentic STEM experiences (Campbell, Speldewinde, Howitt, & MacDonald, 2018). Part of building professional self-efficacy and expertise lies in educators refining their knowledge and practice through reflection and enaction (Clarke & Hollingsworth, 2002). This poster presents an innovative theoretical model that contextualises STEM education in Early Childhood (Figure 1), and is proposed to assist educators to explore how they may engage with the elements required to build their self-efficacy to enact authentic and rich STEM learning practices. A sustained professional learning series that is funded by a regional South Australian, Department for Education partnership, which explores Early Childhood educators’ professional growth is the context for this study and will utilise a case study approach informed by Clarke and Hollingsworth’s (2002) Interconnected Model of Professional Growth as a theoretical foundation. This poster will present the key ideas from the literature that will inform the research project and enable educators and researchers the opportunity to reflect on the processes and conditions in which teachers experience professional growth in a STEM context.

Keywords: Early childhood, STEM education, professional learning
THE ICREATE PROJECT: LONG TERM COMMUNITY PARTNERSHIPS AND THEIR ROLE IN STEM EDUCATION

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ABSTRACT

This study examines the implementation of a novel model for community involvement in STEM education in a secondary level bioscience course in the United States. This course is designed to engage students in an authentic problem important to the local community while drawing upon community resources within the bioscience context. Specifically the course engages students with community partners as they examine the community-focused issue of tracking influenza-like illnesses across the region. The project emanates from efforts in education designed to develop the next generation of STEM innovators who can productively participate in our increasingly global society. The overall goal of the project is to positively affect the interest and motivation of students to continue in STEM fields in order to increase the STEM workforce in the region. The study utilised a multi-methods approach to examine the ways in which community partners interacted in the project and the impact of collaboration on the partners themselves. Data sources include both quantitative and qualitative measures. Initial results reveal a high degree of continuity and engagement amongst the partners. The results of this study will inform community-based interventions in STEM education.

Keywords: STEM careers, identity, self-efficacy
JINDAOLA, AN ABORIGINAL WAY: EMBEDDING KNOWLEDGES AND
PERSPECTIVES ACROSS A TERTIARY STEM FACULTY

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ABSTRACT

Jindaola is a project within an Australian University in partnership with
local Traditional Owners from the Yuin nation that seeks to enrich the
experience of all students at the University by embedding Aboriginal
knowledge in the curriculum. Jindaola is the Yuin term for goanna and
represents a philosophy of practice, based upon the principles of respect,
responsibility and reciprocity. It is a reciprocal learning/teaching process
for staff involved, who are on their own journey of personal development,
learning the Aboriginal way of sharing knowledge as they embed these
knowledges in the curriculum. This study reports on these two facets of
the project: 1. The process of academic development of the non-
Aboriginal staff involved in the initiative and 2. The trial of an educational
intervention aimed at increasing science student’s awareness of local
Aboriginal knowledge and culture. The curriculum innovations to be
discussed are components of a larger project that aims to better reflect the
breadth and depth of knowledge in our society through embedding
Aboriginal ways of knowing, being and doing in university curriculum.
Our recommendations for others wishing to follow a similar path is to
include consultation with community and Aboriginal staff must be leaders
of the change process. Additionally, meaningful time needs to be spent
allowing non-Aboriginal academic staff members to gain an appreciation
and deep respect for the depth and complexity of Aboriginal knowledges
before any curriculum modifications can be developed and implemented.

Keywords: Aboriginal, Indigenous, Knowledge, Jindaola
FROM STEM TO STEAM: THE ROLE OF ARTS

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ABSTRACT

The rapidly changing knowledge and information society of the 21st century is forcing STEM towards STEAM. The deep integration of social expectation art can balance the disadvantages of education only around science and technology. However, STEAM now faces the challenge of how art can be connected and how to fit into STEM. In fact, "A" in STEAM contains five elements, such as fine art. It conveys six-dimensional concepts, such as the great art perspective. It has four functions, such as improving creativity. Hetland et al. provided a model for the successful docking of art and STEM education with studio thinking. Bresler provides the necessary support and structure for the integration of art into STEM education. STEAM education will be a hot issue in education for a long time to come. There are three Suggestions for further development of STEAM education. The first is to emphasize the concept of interdisciplinary, the second is to emphasise the practice based on art, and the third is to excavate the appropriate education resources.

Keywords: STEM, STEAM, Arts, Science Education
DESIGN THINKING AND COLLABORATIVE INQUIRY IN STEM: IMPLICATIONS FOR COMPETENCY DEVELOPMENT

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ABSTRACT

The study involving 151 Year 6 students and their teachers, explored student learning, competency development and engagement with engineering design thinking tasks across two groups of students. One group participated in inquiry design thinking curriculum alone (N = 86) and another group participated in inquiry design thinking curriculum in addition to collaborative philosophical inquiry (CPI, N = 65). Students in the combined CPI and design thinking inquiry curriculum group showed significantly higher learning gains, knowledge, STEM-based competencies and accurate use of scientific language and representations. The study showed that while students’ demonstrations of STEM epistemological and subject competencies significantly improved across a unit of work that featured inquiry and STEM design thinking tasks, also participating in CPI dialogue as well resulted in more significant improvements on all measures. Students in the combined CPI and design thinking inquiry curriculum group showed a wider range of competencies that translated into significantly higher learning gains. The study demonstrates how CPI enhances epistemological and subject-based competencies in science, technology, engineering and mathematics. CPI promotes a strong inquiry process throughout STEM design thinking tasks resulting in restructuring or reshaping of the design process and thinking/idea creation.

Keywords: Collaborative philosophical inquiry, competencies, design thinking, STEM
THIS IS US: HOW ONE SYDNEY SCHOOL USED STEAM TO GROW THEIR COMMUNITY

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ABSTRACT

What if you teach high school students to learn mathematical theory of Cartesian plotting and graphing within the context of Art and Design? How is this playful and fearless, demonstrating curiosity and purpose? (Wagner, 2012). How do we label this learning? We call this STEAM at its trans-disciplinary zenith. It is possibility with a capital P. Mixed methods research was employed via participatory observation to gather qualitative and quantitative data related to secondary school learning experience using the parabolic curve as the primary point of departure for student creation of three-dimensional aesthetic objects. The objects themselves relate to the concept of vessel; a container, a receptacle, a holder of something. Documenting the inter-disciplinary approach resulted in an exploration of the complexities we employ to discover meaning in a range of contexts not especially reliant on singular language. Convergence is presented in that mathematical rules unite with the rules of art and design in the attempt to project new concepts into situations where a space for originality exists. Here, the students have been encouraged to imagine new, effective ways of bringing ideas to form (Richmond, 2009). Naturally, developing explicit appreciation/action situations required critical and creative thinking to coincide with lateral and literal approaches to gaining knowledge and understanding of aesthetics. The study presents a reflexive account of the delivery of coursework entitled The Possibilities of the Parabola, from concept to completion.

Keywords: STEM, STEAM, trans-disciplinary, inter-disciplinary, cross-curricular
USING COMBINED RESEARCH SYNTHESIS AS A (NOVEL) APPROACH FOR EXPLORING TEACHER SELF-EFFICACY IN INTERDISCIPLINARY STEM

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ABSTRACT

Playing a key role in teaching effectiveness (Tschannen-Moran & Hoy, 2007) and positive student outcomes (Guo, Connor, Yang, Roehrig, & Morrison, 2012), the importance of teacher self-efficacy in education is supported by a considerable research base. The link between teaching effectiveness and student success (Hanushek, 2011), alongside the recent focus on interdisciplinary STEM education for producing students that are innovative 21st century individuals (Nadelson & Seifert, 2017) suggests the question; could teacher self-efficacy for interdisciplinary STEM education be important for attaining effective teaching in this domain? This project uses a combined research synthesis to explore this question and its achievement in teacher education.

With limited literature exploring teacher self-efficacy in interdisciplinary STEM education, a combined research synthesis is proposed as a method for developing a teacher education model. Data from existing empirical studies across the independent contexts of ‘teacher self-efficacy development’ and ‘interdisciplinary STEM teacher education’ is collected and united. This combined synthesis creates an evidence base for a teacher education model for building self-efficacy in interdisciplinary STEM. This poster illustrates the methodology and presents one such model for discussion. As a relatively novel approach in education, research synthesis requires consideration and critique to explore its possible benefits, limitations and challenges. Participants are encouraged to explore, critique and discuss the model presented. Does the model depict self-efficacy development in teacher education for interdisciplinary STEM? Has combined research synthesis achieved the aim of being a novel approach for exploring teacher self-efficacy in interdisciplinary STEM?

Keywords: STEM education, Interdisciplinary/integrated STEM education, teacher education, self-efficacy, research synthesis, 21st century skills
EUREKA! THE ARCHIMEDES’ PRINCIPLE THROUGH THE STEM APPROACH

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ABSTRACT

The story of Hierao’s king’s crown is widely taught in scholar books. The questions are: is this story true? How did Archimedes unravel the riddle? These questions were presented to the 12th grade students in two videos with different perspectives about the Archimedes’ history and principle. After watching the medias, the scholars reflected about the history of Science, found similarities & differences between both versions and decided which one they believe, showing arguments in a presentation. In order to compare the versions, the students performed tests in a hands-on lab activity that simulates the crown’s story and the capacity of a ship. During this activity, the students were challenged to explore and to determine density & volume of different objects by displaced fluid and to plan the maximum cargo of floating. The results of these experiments were calculated, compared with the experiments showed in the videos, analysed with technological tools and discussed based on the theory learned. After confronting different versions of science’s knowledge, the students elaborated a conclusion confirming or refuting the initial argumentation, building concepts about density and floatability and the Archimedes’ principle. Besides that, they discovered that history and science are made of many versions. So, which version is the correct one? Maybe we’ll never know. This presentation intent to show the class and promoting a discussion about how the STEM components are applied to solve a scientific challenge and to learn the Archimedes’ principle trough different versions of science and history.

Keywords: Archimedes, history of Science, challenge
STEM EDUCATION IN THE EARLY CHILDHOOD YEARS: PROMOTING STRONG FOUNDATIONS FOR FUTURE DEVELOPMENT

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ABSTRACT

Early childhood education and care (ECEC) pedagogy provides an opportunity to engage young children in quality STEM learning experiences prior to attendance at formal school settings. Young children are capable of learning mathematics and science concepts (e.g., Baroody & Dowker, 2003; Greenfield et al., 2009) and by providing strong foundations in STEM, this learning has been associated with school readiness and academic achievement (e.g., Arnold, Fisher, Doctoroff, & Dobbs, 2002; Duncan et al., 2007). Despite this, while ECEC educators may be keen to incorporate STEM into their curriculum, more support and knowledge about developmentally appropriate STEM experiences are needed (Linder et al., 2016; McClure et al., 2017). Given the importance of smooth transitions between ECEC settings and formal schooling, it is vital primary educators understand and appreciate learning that occurs in ECEC contexts to ensure ongoing success for all children. Preliminary results from a case study provide insight into educational practice in an ECEC setting in order to identify examples of effective STEM pedagogy. Not only will this provide ECEC educators with examples of STEM experiences for young children, primary educators will be able to broaden their understanding of the knowledge and experiences of children moving into their settings. Overall, the preliminary findings of this case study will increase understandings of ECEC STEM pedagogy and help to inform strategies that strengthen STEM learning across transitions from ECEC to primary school settings.

Keywords: STEM, ECEC, Transition, Age-appropriate pedagogy
CREATING A REALITY-RELATED AND DISCIPLINE-INTEGRATED SITUATION FOR STEM LEARNING WITH AUGMENTED REALITY TECHNOLOGY—WITH AN EXAMPLE OF URBAN CIRCUIT PLANNING

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ABSTRACT

Inspiring students to think with a reality-related and discipline-integrated perspectives is very significant in a STEM course. In this study, we attempt to illustrate the role that augmented reality (AR) can play to create a situation in an introduction part of a STEM course. We believe that AR can encourages students think with interdisciplinary knowledge to solve realistic questions and develop their inquiry ability. To show how AR works, we designed and developed an application with augmented-reality technology, City of Light. 33 pre-service STEM teachers tested this application with related scales and compared it with a flash programing. According to the results, AR benefits a lot in not only creating reality-related and discipline-integrated situation, but also improving students’ inquiry ability.

Keywords: STEM, situation, augmented reality