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EDITORIAL

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Burgeoning Research in STEM Education in Australia is a special issue of J-STEM that illustrates the breadth of STEM education research being undertaken in Australia. Showcased is research that investigates STEM education implemented in various educational settings and how implementation is influencing student learning, supporting teacher practice, informing the delivery of the curriculum, and shaping the nature of schools. This special issue captures the diversity and complexity of the STEM education research undertaken.

STEM education and associated research in Australia are nascent form. The emergence of the STEM term came to prominence in Australia in 2010 when the Office of the Chief Scientist championed the need for improving the flow of graduates into the STEM fields. Although STEM education research was underway at the time, the Chief Scientist brought a sense of importance and urgency to the need for research to inform practice. Since then, the research field of STEM education in Australia has grown considerably.

In Australia, as in other countries, the conundrum of the STEM acronym preoccupies the rhetoric about theoretical conceptions of STEM. The ambiguity of using the STEM acronym when referring to the disciplines as a collection of individual disciplines as well as when referring to the interdisciplinary nature of the disciplines is compounded further by the emergence of other acronyms, such as STEAM (Fraser, Earle, & Fitzallen, 2019). In their article, MacDonald, Hunter, Wise, and Fraser focus on the spaces between STEM and STEAM to elucidate the benefits of broadening our notion of interdisciplinarity in those contexts. Their article challenges readers to step out of their respective disciplines and consider the possibilities and benefits of working with other disciplines to shape education.

Interdisciplinary learning is at the core of the activity implemented with Year 5 students by Fitzallen, Wright and Watson. The activity involved designing and trialling seed dispersal devices. This provided an engaging Science context within which learning was based on the intersection of two frameworks, the engineering design process (Katehi, Pearson, & Felder, 2009) and the practice of statistics (Watson, Fitzallen, Fielding-Wells, & Madden, 2018). This allowed for the exploration of the direct inter-relationships of the disciplines of Mathematics and Engineering within that context. Fitzallen and her colleagues draw attention to the need to plan specifically for outcomes in all disciplines relevant to an activity to shift learning for some disciplines from being incidental to bring purposeful and potentially developmental.

In their article, Anderson, Wilson, Tully and Way examine the outcomes of supporting teams of teachers to plan, deliver, and evaluate integrated STEM learning activities. Based at the STEM Teacher Enrichment Academy, the authors delivered a professional learning program that involved students designing and constructing a wind powered car. As well as reporting on positive outcomes for the students and teachers involved in the project, Anderson and her colleagues report on the benefits of engaging with members of the local community and the role they can play in shaping student learning outcomes. They also point out that it is imperative schools take a lead in making STEM learning sustainable by building teachers' capacity to deliver STEM learning through continued professional development, revitalised school curricula, and changes to the structure of schooling.

Fraser, Beswick and Crowley also report on a project that involved working with teachers. Their research included novice and experienced teachers of STEM subjects from schools in rural, regional, and remote (RRR) Australia and was based on a peer-mentoring model of delivery. The project, STEMCrAfT, was designed to support teachers to evaluate and select appropriate STEM resources. In their article, the attention was on investigating the participants' perceptions of the enablers and inhibitors of effective teaching of STEM in RRR school contexts. Interestingly, principals and school leadership were cited as major contributors to potential solutions to issues faced. Also, of benefit were parental engagement and understanding of the importance of STEM education, and contributions from community members.

Mentoring through the provision of role models was a key component of the study reported by Barkatsas, Cooper, and McLaughlin. In their article, they illustrate the benefits of providing learning opportunities that emphasise the development of STEM skills in creativity, design, entrepreneurship, problem solving, adaptive thinking, and digital literacy. Outcomes of the Women in STEM (WISE)-STEM in Situ project comprised the potential of building of students' STEM self-identity so they could be creators of their own futures and the benefits of exposure to STEM equipment and resources not utilised or available in school facilities. The article serves the STEM education research community further by reporting on the development and implementation of a survey, STEMTAS, to measure affective changes as a result of participating in innovative and challenging STEM learning opportunities. The authors suggest the survey is one way of monitoring affective changes that may influence students' future studies and career aspirations.

This special issue ends with a book review written by Richelle Marynowski, from the University of Lethbridge. The book, STEM Education: An Emerging Field of Inquiry (2019), aims to support STEM teaching and learning during the compulsory years of schooling and beyond. The book also draws attention to the way in which research conducted in the Australian context aligns with STEM education research conducted in other countries. Collectively, the articles in this issue provide insight into what constitutes STEM education and practices in Australia could be used to further STEM teaching and learning internationally.

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RESEARCH REPORT

Focusing on Data: Year 5 Students Making STEM Connections

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Abstract: *Integrated STEM learning experiences provide the opportunity for students to make connections among the various disciplines. The outcomes for many STEM activities, however, are only reported for one discipline and provide little guidance for taking an integrated approach to learning in the classroom. This paper reports on a Year 5 STEM activity based on designing, making, and trialling seed dispersal devices. A focus on the data collected by the class and the subsequent graphical representations created during follow-up interviews, illustrates the way in which the students made connections to multiple STEM disciplines. The results indicate that Year 5 students have the capacity to use graphical representations of data to describe the performance of seed dispersal devices and base informal inferences about the performance of the devices on their knowledge of design, construction, materials, and flight from the various STEM disciplines.*

Keywords: STEM education, Graphical representations; Variation; Practice of Statistics

STEM (Science, Technology, Engineering and Mathematics) learning experiences that take an integrated curriculum approach provide students with the opportunity not only to learn content but also to apply that knowledge within meaningful real-life related contexts. Unfortunately, implementation of such activities has resulted in little change in pedagogical practices and has not given rise to new ways of conceptualising the Australian Curriculum (Blackley & Howell, 2015). Blackley and Howell, and others (e.g., Fitzallen, 2015), lament the lack of evidence-based guidance for teachers to implement change and the pressure placed on teachers to deliver STEM learning outcomes within a curriculum with discrete subjects for each discipline. Compounding the issue is that the Australian Curriculum does not include Engineering as a subject (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2019). The recent release of the Australian Curriculum: Design and Technologies has gone some way to alleviating the issue by including engineering-related practices such as designing, creating, modelling, critiquing and evaluating. Although the Design and Technologies curriculum states that students will create designed solutions for the technological context of "Engineering principles and systems", the content descriptors do not refer explicitly to engineering. The subtle way in which engineering principles and systems are included in the Design and Technologies curriculum does not give the discipline of engineering the same standing in the Australian Curriculum as the other disciplines included in the STEM acronym.

STEM integration is often reported in relation to the number of disciplines addressed purposefully in a learning activity (e.g., Becker & Park, 2011; Fraser, Earle, & Fitzallen, 2019). With a focus on engineering, Moore and Smith (2014), however, offer two different ways to integrate

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curriculum content with engineering design principles: Context integration and Content integration. Context integration refers to using the engineering design process to help students learn the subject knowledge from the other STEM disciplines, primarily mathematics and science. In these instances, the engineering design process is the main learning focus and is used as a step-by-step model to structure learning. This also includes taking advantage of the cyclical nature of the process when designed solutions are reviewed and modified (e.g., English, Hudson, & Dawes, 2013; Ward, Lyden, & Fitzallen, 2016). Unfortunately, research that reports outcomes from taking a context integration approach often only reports on the outcomes of implementing the engineering design process and rarely reports on the outcomes associated with the subject content knowledge encompassed in learning activities.

Content integration refers to the integration of engineering thinking and subject knowledge where the focus is on delivering engineering content and STEM discipline knowledge as learning goals (Moore, Guzey, & Brown, 2014). Again, research that takes this approach mostly reports on the engineering outcomes (e.g., English et al., 2013; Ward et al., 2016) and rarely includes the potential outcomes for the other STEM disciplines encompassed in the learning activities. The dichotomy set up between the two integration models proposed by Moore and Smith (2014) does little to support teachers wanting to take an holistic integrated STEM approach in the classroom. An amalgamation of context and content integration seems desirable but research on the implications of such an approach is sparse.

In recent times, more holistic conceptual models of STEM have emerged from the literature (e.g., Kelley & Knowles, 2016; Lowrie, Leonard, & Fitzgerald, 2018). The conceptual model proposed by Kelley and Knowles is a five-part model that includes the way in which people learn and work within the four STEM disciplines: engineering design, scientific inquiry, technological literacy, and mathematical thinking. The model also includes a Community of Practice (Lave & Wenger, 1991) as the element that facilitates integration. Kelley and Knowles go further to propose that the engineering design process provides the context and the platform for STEM learning. The emphasis on the engineering design process and the addition of the community of practice in the Kelley and Knowles conceptual model of STEM increases the complexity of the notion of STEM and may limit its applicability. As it stands, the conceptual model does not account for STEM learning that is not embedded within engineering design contexts. Also, including the community of practice element is problematic. A community of practice in the school context relies on community experts (e.g., practicing engineers) to mentor novice learners. The opportunity to invite experts into classrooms and for them to engage with learners as they work through design projects for a sustained period is not always possible due to the uncertain proximity and availability of experts, and the time demands such an approach places on teachers and experts alike.

The conceptual model developed by Lowrie and his colleagues (2018) presents a broader model than the one developed by Kelley and Knowles (2016). Like Kelley and Knowles, Lowrie and his colleagues developed a model that does not address STEM discipline content specifically. It is a heuristic based on a pedagogical approach related to the early years of schooling (K-Year 2): Experience, Represent, Application. This model emphasises the importance of giving students the opportunity to have hands-on experiences that build on their prior learning and extend their understanding beyond the immediate context of the new learning, which is relevant to all levels of schooling. Although a simple model to enact in the classroom, the lack of acknowledgement of the way in which students learn in the various STEM disciplines in the model may result in learning experiences being driven by subject content knowledge, thereby, potentially limiting the heuristic as a way of promoting integrated STEM learning.

The recent emergence of the models of Kelley and Knowles (2016) and Lowrie and colleagues (2018) positions these new ideas from the literature as theoretical frameworks and would benefit from research to validate and refine them. More research that reports findings about STEM learning holistically using integrated STEM learning models, from an inter-connected perspective, is needed. This would provide evidence-based practical applications, programs or interventions to address integrated STEM learning (Honey, Pearson, & Schweingruber, 2014; Rosicka, 2016) and allay concerns that developing subject content knowledge is secondary to improving student engagement and motivation in the primary classroom (Fitzallen, 2015; Shaughnessy, 2013). This paper aims to add to the discourse about what constitutes integrated STEM learning. It seeks to illustrate the way in which students make connections to the STEM disciplines when the context integration is focused on the engineering design process and the content integration is focused on mathematics learning outcomes. The research question addressed is, "What connections do students make to the various STEM disciplines when conducting an investigation that is framed by the engineering design process and focused on developing outcomes in data and statistics?"

Research Background

The research reported in this paper draws on two conceptual frameworks – the Engineering Design Process (Kelley & Knowles, 2016) and the Practice of Statistics (Moore & McCabe, 1989; Watson, Fitzallen, Fielding-Wells, & Madden, 2018). The engineering design process underpins the integrated STEM framework proposed by Kelley and Knowles. It includes:

1. *Identify problem* – the engineer must be fully aware of what the problem entails and how this may affect people.
2. *Brainstorm solutions* – the engineer thinks of any ideas (both possible and improbable) that may lead to a suitable solution to the identified problem.
3. *Design* – the engineer will select one of the most suitable ideas developed in the brainstorm phase and start to create a full design for this idea.
4. *Build* – the engineer will build a prototype of the design.
5. *Test and evaluate* – the engineer will test the prototype under suitable conditions and assess its performance based on the established understanding of the problem.
6. *Redesign* – the engineer will identify features for improvement, which are redesigned and modified. (Ward et al., 2016, p. 11).

In the engineering design process there is an explicit understanding that modified devices or models would undergo retesting and re-evaluation. Although useful for framing learning experiences, Kelley and Knowles acknowledge that the engineering design process is limited because it does not account for STEM learning that is not embedded within engineering design learning experiences.

The practice of statistics was chosen as a conceptual model to underpin the mathematics content covered by the activity implemented in the classroom. The practice was first conceptualised by Moore and McCabe (1989) as a way of initiating curriculum reform in higher education statistics courses. Watson and colleagues (2018) extended these ideas by demonstrating the way in which the practice of statistics applies to the compulsory years of schooling. The practice of statistics is based on the way in which statisticians work and the premise that "statistical problem solving and decision making depend on understanding, explaining, and quantifying the variability in the data" (Franklin et al., 2007, p. 6) throughout an investigation. The steps in statistical problem solving outlined in the Guidelines for Assessment and Instruction in Statistics Education (GAISE) Report (Franklin et al.) are:

i. Formulate Questions,
ii. Collect Data,
iii. Analyse Data, and
iv. Interpret Results.

Like the engineering design process, the practice of statistics facilitates a cyclical review of results and promotes collecting more data to measure improvement, confirm results, or make comparisons. Similarly, the practice of statistics is not relevant or applicable when the way in which real-life situations are examined does not require data.

Individually, the engineering design process and the practice of statistics are limited in reach as integrated STEM learning models but do share similarities. The engineering design process provides students with a systematic approach to solving problems based on designing, constructing, and testing the performance of design solutions (Kelley & Knowles, 2016). The practice of statistics also facilitates a problem-solving approach but focuses on the collection of data to make evidence-based decisions (Watson et al., 2018). It seems logical that considering the two frameworks in tandem may enrich students' STEM learning experiences.

The alignment of the engineering design process and the practice of statistics is illustrated in Figure 1. Although organised in Figure 1 as two separate entities, the enactment of integrating the two processes within a STEM investigation potentially results in an amalgamation of student actions and ideas from the two processes. It is likely one process will have a greater focus than the other at various times during an investigation and that focus would shift to the other process depending on the stage of the investigation. For example, the focus would be on the engineering design process when first designing a prototype and the focus would be on the practice of statistics when collecting and analysing data to measure the performance of the prototype. Later, the engineering design process and the practice of statistics work in tandem when decisions about the modifications to be made are based on the results from the data analysis.

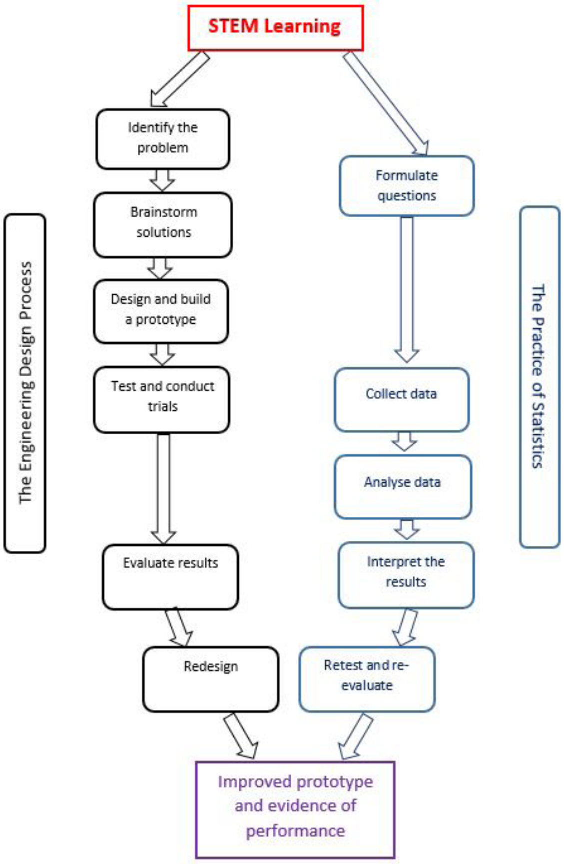

Figure 1: The alignment of the Engineering Design Process and the Practice of Statistics in STEM learning.

For the sake of simplicity, the two models are displayed in Figure 1 in chronological order of implementation during a learning experience, if entry to a project begins with identifying a problem (engineering design process) or posing a question (practice of statistics). This linear representation distorts the dynamic nature of an investigation and the capacity of both frameworks to initiate student engagement at any stage of either framework. In relation to the implementation of the practice of statistics, for example, Watson et al. (2018) illustrate the way in which students compared the difference in manufacturing licorice by hand or machine when the question posed, and the method of data collection were already established by the teacher. Similarly, entry into the engineering design process could occur when students are given a device and asked to improve its performance, even though they may not have been involved in the original design and construction of the device.

According to the Increasing Levels of Integration continuum described by Vasquez (2015), the integration of the engineering design process with the practice of statistics would be considered multidisciplinary integration. At the multidisciplinary level of integration, “Students learn concepts and skills from two or more disciplines that are tightly linked so as to deepen knowledge and skills” (p. 13). Learning experiences at this level of integration go beyond learning about concepts and ideas through a thematic approach in separate subject areas, which is characteristic of multidisciplinary integration. The level of integration for this study does not extend to transdisciplinary integration because the investigation that the students conducted was largely teacher-directed and contained within the one learning activity.

Research Approach

This research draws on qualitative research methods and techniques (Creswell, 2014; Johnson & Onwuegbuzie, 2004) to explore the way in which students make connections among the STEM disciplines from the creating and trialling of an engineered device. Evidence of the connections made were collected via student interviews.

A semi-structured interview schedule was developed to guide the interviewers. Semi-structured interviews provide a depth of data that is difficult to gather by other means (Fontana & Frey, 2003). They provide the opportunity for ideas expressed to be clarified and expanded. In this way rich, descriptive data are collected (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). Silverman (2003) warns, however, that although qualitative data collection methods, such as interview, provide valuable information about "how people see things," the methods often ignore the importance of "how people do things" (p. 359). This concern was addressed in this study by conducting the interviews while students used the educational data analysis software, TinkerPlots (Konold & Miller, 2015), to create data representations and analyse the data collected from the design activity.

To draw out students' understanding of data and statistics, and more specifically variation within the STEM context, as evidenced in graphical representations, the interview questions were based on the four categories of Shaughnessy's (2007) student understanding of graphs framework:

- *Read the data*: Recognising components of graphs.
- *Read within the data*: Understanding relationships among elements of graphs and the data.
- *Read beyond the data*: Interpreting information in the graph.
- *Read behind the data*: Looking for possible causes and implications of variation in the data.

The first three categories of Shaughnessy's framework were proposed by Curcio (2001), who considered school students' interpretation of graphs from the three perspectives. The additional category proposed by Shaughnessy, Read behind the data, gave the Curcio model greater depth in terms of the way students develop graph sense. It also attended to the importance of using data for a purpose, for example, to make decisions and informal inferences (Makar & Rubin, 2009).

The reason for focusing on the students' understanding of graphs was to identify the connections the students made from the mathematical content associated with data and statistics covered by the investigation to the ideas and concepts related to the other STEM disciplines. The assumption was made that a discussion about the data collected within a meaningful STEM context would prompt the students to think more broadly about that context. As Rao (1975) posits, statistics require data and data require context. The decision not to ask direct questions about the connections the students made to the STEM disciplines in the interview was to alleviate the issues associated with asking leading questions (Kvale, 1996). The aim was to let the connections the students made emerge from the interviews, which is in keeping with the exploratory nature of the study (Creswell, 2014).

The Study

The activity that was the setting for the study reported here was the seventh implemented for one of the schools in the longitudinal project, Modelling with Data: Advancing STEM in the Primary Curriculum, which followed students from the middle of Year 3 to the end of Year 6. The activity reported here took place near the end of Year 5. The aim of the overall project was to build on the potential of the practice of statistics to enhance STEM learning as the students developed understanding of working with data, which is the basis of the practice of statistics (Watson et al., 2018). The STEM activities provided the contexts within which data were collected, analysed, and interpreted. Indeed, as Rao suggested in 1975, "Statistics should not be taught as a separate discipline, as the sole purpose is to inculcate in the students quantitative approach and thinking, and this cannot be done without reference to real problems" (p. 161). The project had ethics approval from the Tasmania Social Sciences Human Research Ethics Committee (H0015039).

In Year 3 the first activity focused on the advantage of consistency in a manufacturing process by comparing the variation in the mass of a product made by hand and by machine (Watson, Fitzallen, English, & Wright, 2019). The second activity expanded the sources of variation by considering the difference in the change in temperature of insulated and non-insulated cups initially filled with hot water and placed in a water bath of cold water, followed by the introduction of ice in the water bath 10 minutes later (Fitzallen, Wright, Watson, & Duncan, 2016). This activity, focusing on heat, expanded the appreciation of ways to represent data in graphical formats (Fitzallen, Watson, & Wright, 2017).

At the beginning of Year 4, the focus expanded to include the posing of questions in the practice of statistics, as students posed questions to become acquainted with students and their environment in a sister school in another state (English, Watson, & Fitzallen, 2017). After collecting the data, using an on-line survey to deliver the questions, they again analysed and interpreted their data (Watson, Fitzallen, & Wright, 2019). More focus was placed on the engineering design process along with the Science topics of force and energy at the end of Year 4 when students considered the performance of a basic catapult to launch an object and then whether "improvements" meant that the catapult would launch the object further (Fitzallen, Watson, Wright, & Duncan, 2018). In Year 5, students undertook two activities related to the Science topic of viscosity. First, they collected data on several different densities of a substance to find the concentration of a mystery density, and then simulated lava flow down a model of a "volcano" to determine the time needed to travel a distance beyond the distances for which the data were collected (Fitzallen & Watson, in press).

By the end of Year 5 it was felt important to focus more on the design-and-build elements of the engineering design process (Figure 1) and to use data to make decisions about design modifications. Hence the decision was made to consider a design problem in a Science topic: the device by which plants disperse their seeds in the wind. This report focuses on the student interviews conducted 8 weeks after the implementation of the classroom activity.

Implementation of the Study

Fifty-four Year 5 students in two classes at an urban independent Catholic school participated in all stages of the seed dispersal activity. To set the scene for the activity, the classroom discussion focused on sustainability, the need for the conservation of plant species, and the methods plants use to disperse seeds covered by the cross-curriculum priority of Sustainability, outlined in the Australian Curriculum (ACARA, 2019). The activity implemented in the classroom was based on the topic of wind dispersed seeds (adapted from Pike, 2017), which required students to construct a seed dispersal device to carry a seed as far as possible.

Based on the integrated STEM framework that included the engineering design process and the practice of statistics (Figure 1), the Year 5 students enacted the engineering design process when they worked in groups of three to design, create, test, evaluate, modify, and re-test devices to disperse seeds. The groups were assigned one of three types of dispersal devices—sails, parachutes or helicopters—for which each group member built a prototype. The prototypes were constructed from a variety of materials, such as feathers, polystyrene balls, fabric, paper, and wooden sticks. An example of a design drawn, and the prototype constructed (parachute), is shown in Figure 2. A full description of the activity and more examples of devices constructed are reported in Smith, Fitzallen, Watson, and Wright (2019).

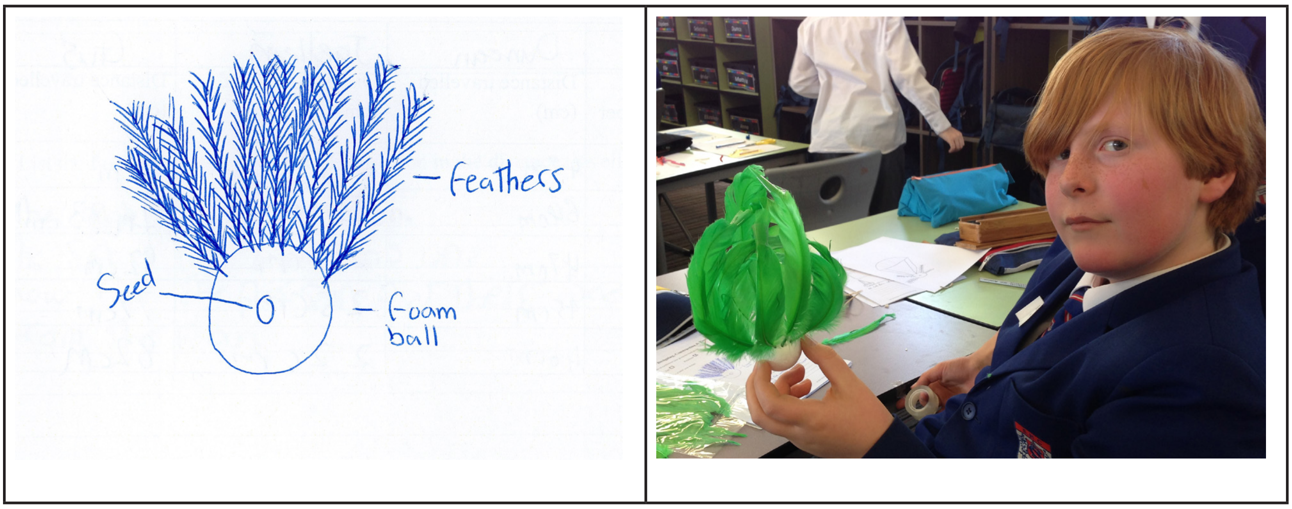

Figure 2. Design and constructed prototype of a seed dispersal device.

The members of each group launched their individual prototypes in front of a free-standing electric fan five times and measured the distance travelled each time (Figure 3). After the data were collected and evaluated, the students used the data and results from the trials to make an informed decision about which prototype was to be modified and re-trialled. The group members then worked together to modify the design and collect more data. They tested the modified design another five times and compared the data to that collected earlier to determine if the modified device dispersed the seed further than before.

Figure 3. Launching a prototype: Sail.

The data from the trials of the modified devices were entered by the third author in TinkerPlots and used to support class discussion about the distribution of the data for each model and the variation in the distance travelled among the results for the three types of seed dispersal devices (Figure 4). These TinkerPlots files were used two months later in individual student interviews.

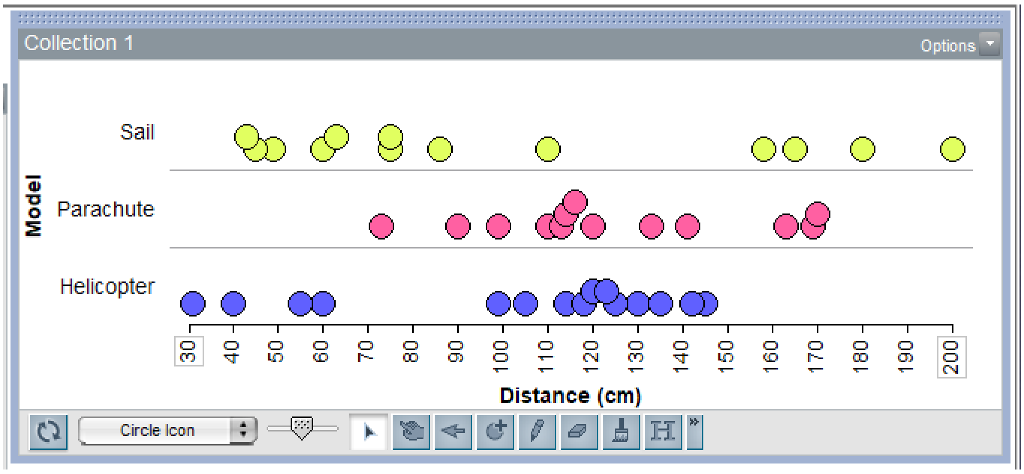

Figure 4. Distribution of data for the three types of seed dispersal devices.

Data Collection: Student Interviews

Of the 54 students who participated in the learning activity, 45 were interviewed by one of three members of the research team, including authors two and three. The selection of students to interview was based on their availability. No students were excluded for reasons other than their absence at the time of the interviews. The age of the participants at the time of interviewing was 11-12 years, and the gender split was 62% male and 38% female.

Each interview lasted approximately 15 minutes. Live screen-capture software was used to record the students' interaction with the TinkerPlots file, and the verbal discussions, which were later transcribed verbatim. Copies of the plots created throughout the interviews were inserted into the transcripts to assist with analysis and interpretation of the students' comments. The data from the interviews were deidentified and are reported using unique codes for each student. For example, [ID789].

The interviews began by asking the students to recall the seed dispersal activity and discuss the processes involved. They were then shown a TinkerPlots file with data collected from their class and told the objective of the interview was to decide if one method of dispersal went the farthest. Initially, the data were arranged randomly on the screen. The students were then encouraged to take control of the TinkerPlots file and manipulate the data display as they deemed appropriate to answer the question. Prompts were given as necessary to assist the students to create a representation that would allow them to make an informed decision (e.g., Figure 4).

The questions asked during the interview were based on Shaughnessy's (2007) student understanding of graphs framework. For example:

- *Read the data: Recognising components of graphs*
  What is the greatest distance travelled by the helicopter seed dispersal device?
- *Read within the data: Understanding relationships among the elements of graphs and data*
  Which seed dispersal device was the most consistent and how do you know?
- *Read beyond the data: Interpreting information in the graph*
  What evidence is there in the plot that helps you decide which seed dispersal method went furthest?
- *Read behind the data: Looking for possible causes and implications of variation in the data*
  If you were to design another model, what would you change so that it goes further than the one you made before?

The semi-structured interview strategy allowed the researchers to ask questions to clarify ideas expressed and probe student thinking, when required.

Data Analysis

Graphical representations. The representations created in TinkerPlots during the interviews were analysed by the second author. A note was made for each representation to indicate the type created (e.g., split stacked dot plot, continuous scale in bins; random display coloured by attribute, Model; unstacked, split dot plot with the attribute Distance on y-axis, continuous scale), and by whom it was created: the interviewer (i), or the student (s). The code "s (prompted)" was used to indicate when a student required assistance to create the representation.

Student interviews. The interview transcripts were read line by line and codes were assigned to students' responses to the questions asked according to the four categories of Shaughnessy's (2007) student understanding of graphs framework. The second author and an experienced researcher in the field individually coded 11 interviews (24%) and then compared their analysis and discussed any discrepancies to come to an agreement. Because the initial level of agreement was 81% and discrepancies were resolved without conflict, it was decided that second author would continue to code the remaining interviews, with the codes established. The total number of instances for each category were tallied to evidence the relative frequency of each category in the data, and comments within each category were compared qualitatively to determine the types of responses provided by the students. As this was an exploratory study, the aim was to establish the way in which students made connections among the STEM disciplines relevant to the classroom activity rather than determine the level of understanding expressed for the content covered for each of the disciplines.

Results

Graphical Representations

Of the 45 students interviewed, one, most likely due to a physical impairment that affects his fine motor coordination, chose not to manipulate the data himself. He was able, however, verbally to direct the interviewer to create a variety of representations and answered all questions without difficulty. The remaining students were all able to manipulate the data and create representations; however, seven required assistance and were prompted to create a suitable final representation to answer the overall question of whether one model went further than the others.

A sample of the final representations created by the 37 students requiring no assistance are shown in Figures 5 and 6. Eighty-nine percent of the students created split dot plots that displayed the attributes Distance and Model (Figures 5a-d). Of these, 11 students (30%) created a split stacked dot plot with Distance along a continuous scale, coloured either by Model (n=8) or Distance (n=3) (Figure 5a, b); seven students (19%) created a similar graph without stacking the data (coloured by Model, n=6, by Distance, n=1); seven students (19%) created a split dot plot with data in bins instead of along a continuous scale (Figure 5c); six students (16%) created plots with Group and Distance, coloured by Model (5 used continuous scales, and 1 had Distance data sorted in bins); and two students (5%) created hat plots, one with vertical reference lines indicating the middle point of each hat, as determined by the student (Figure 5d). Three (8%) of the remaining four students created single variable plots with Distance on either the horizontal or vertical axis (Figure 6a). The data were coloured by Model but lacked a key to clearly distinguish the three models. Lastly, as his final representation, one student chose to remove data values to leave only the Distance travelled by the Helicopters (Figure 6b).

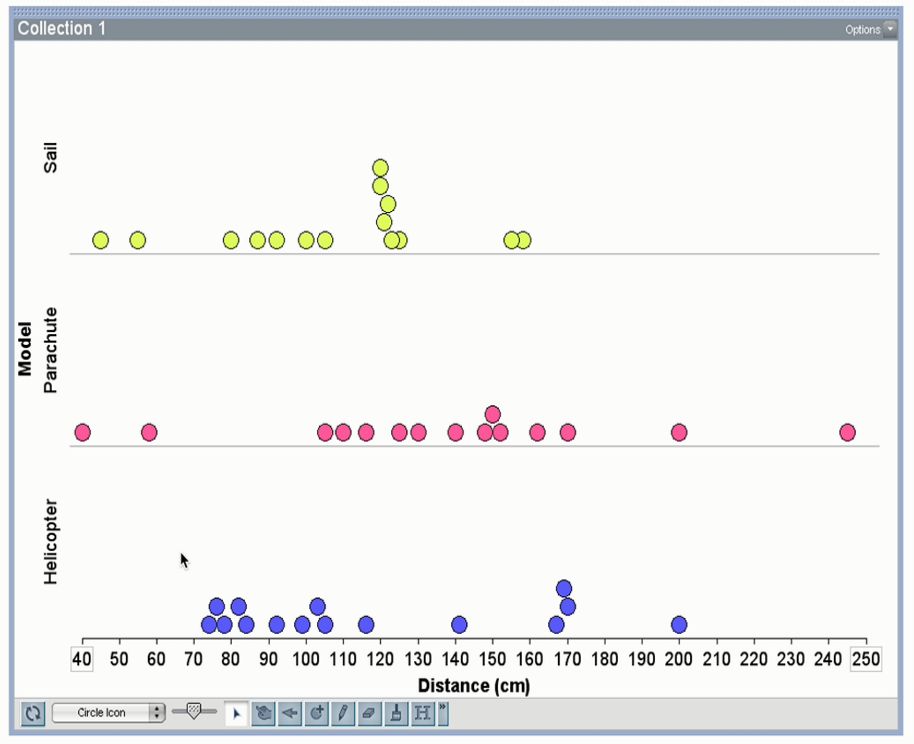

Figure 5a. Split stacked dot plots showing Distance and Model, with continuous scale, coloured by Model (n=8) [e.g., ID159]

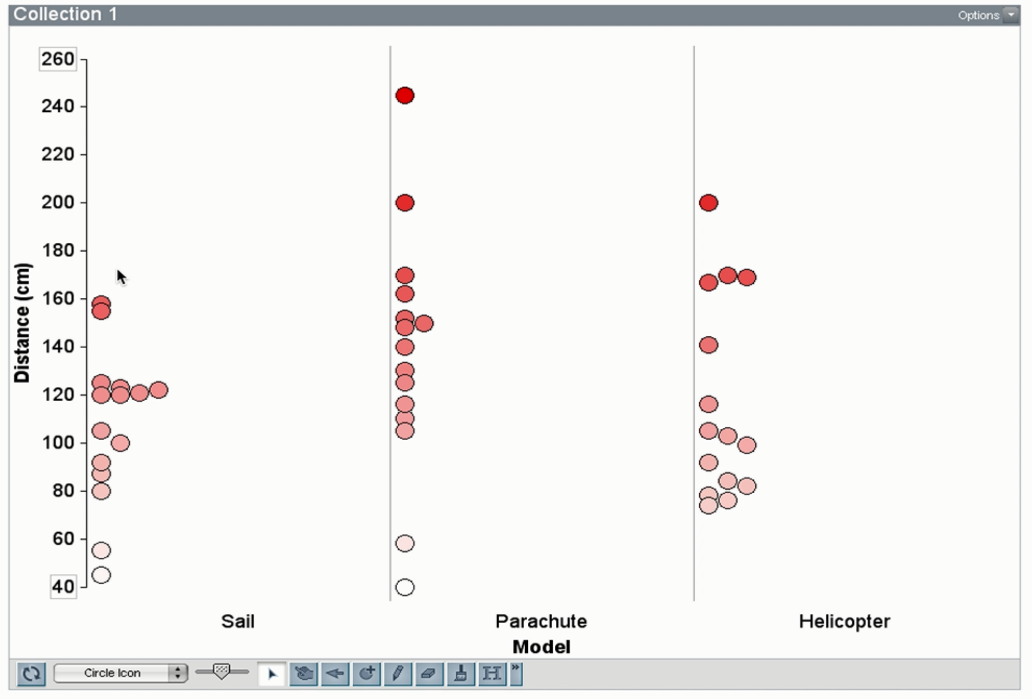

Figure 5b. Split stacked dot plots showing Distance and Model, with continuous scale, coloured by Distance (n=3) [e.g., ID148]

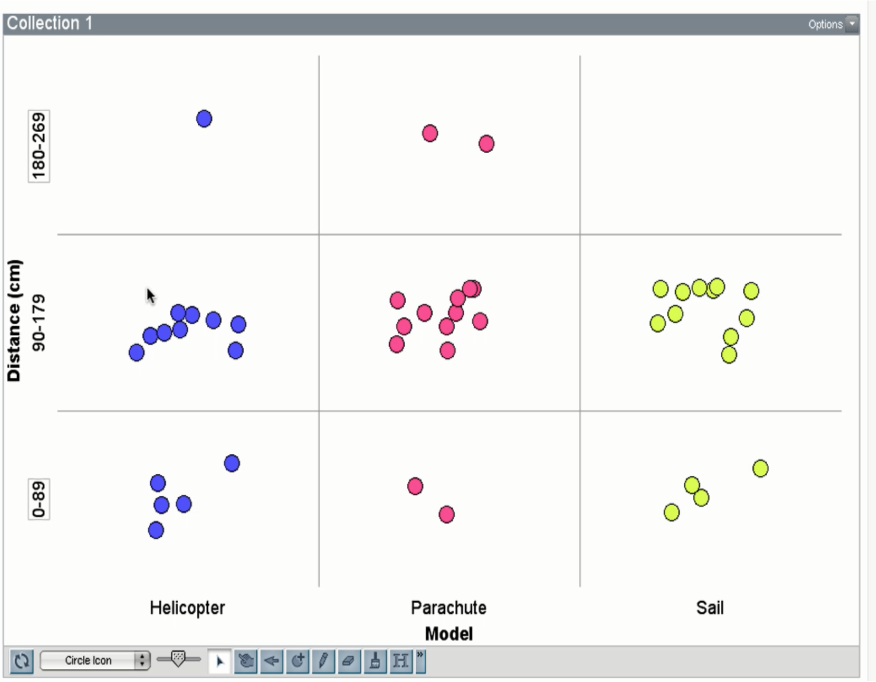

Figure 5c. Unstacked split dot plots showing Model and Distance, with data in bins (n= 7) [e.g., ID149]

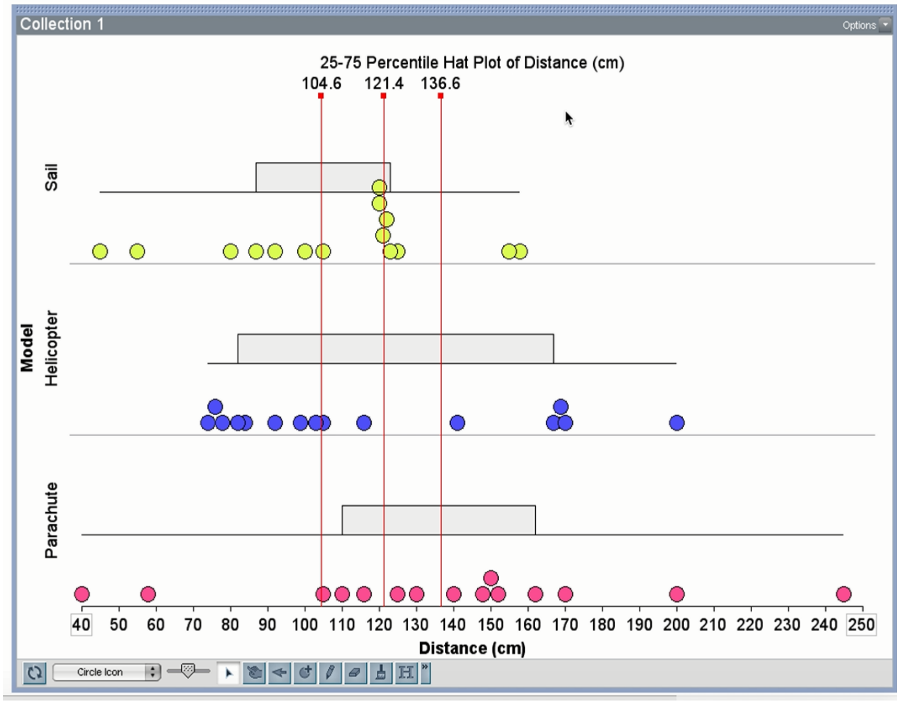

Figure 5d. 25-75 percentile hat plots of Distance (n=2) [e.g., ID161]

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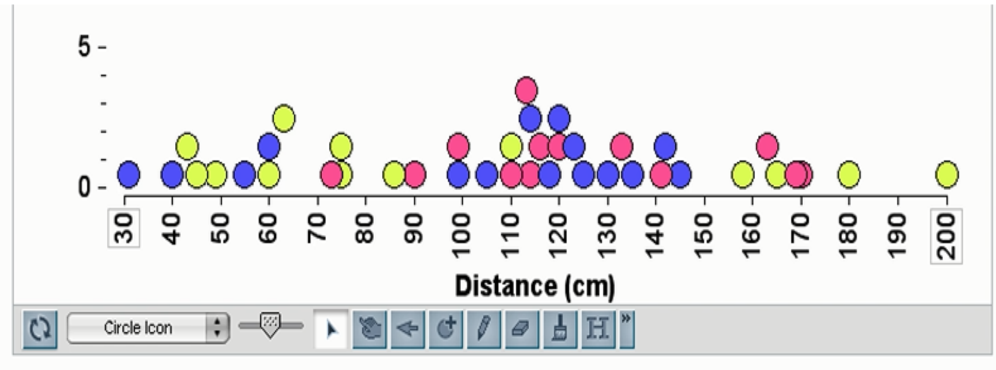

Figure 6a. Single variable plot coloured by Model (n=3) [e.g., ID154]

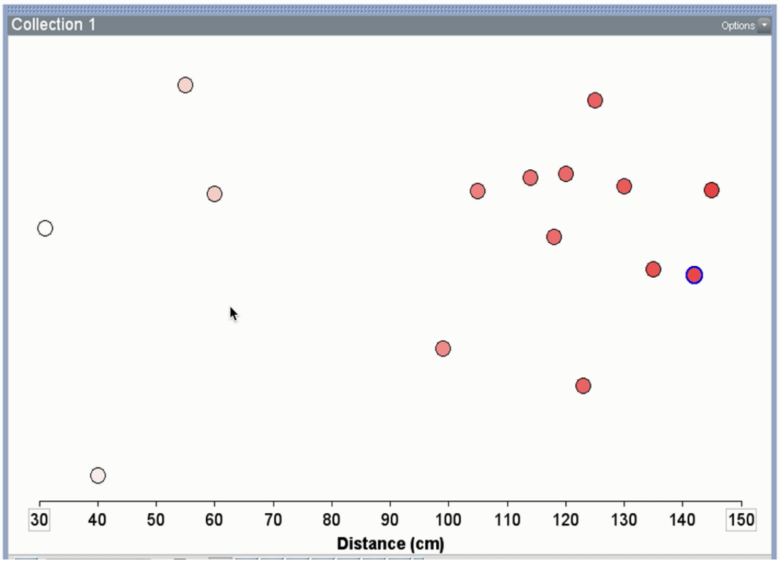

Figure 6b. Distance data for one Model only (n=1) [ID146]

Interview Responses

Across the 45 interviews, the students made a total of 1,029 comments that were coded for the four categories: (i) Reading the data (499 comments, 48%); (ii) Reading within the data (400, 39%); (iii) Reading behind the data (48 comments, 5%), and (iv) Reading beyond the data (82 comments, 8%). All 45 students made one or more data reading comment, and all demonstrated an ability to read within the data (range of 2 to 16 comments each). Twenty-four students (53%) made up to six comments related to reading behind the data, and 27 students (60%) read beyond the data, ranging from 1 to 11 comments each.

Reading the data: Recognising components of graphs. Almost half (48%) of all coded comments related to reading the data and recognising graphical components. In response to direct questions, some students noted a single element; for example, when asked the distance travelled by a specific data case (e.g., *167 centimetres* [ID153]), the model that travelled the shortest or longest distance (e.g., *Umm, the helicopter* [ID131]; *So Group 3 had the furthest one* [ID136]), or the Group number of a selected case (e.g., *Group 1* [ID146]). Others identified multiple data reading elements for the one case (e.g., *The bottom one is 40 centimetres for parachute* [ID148]; *It was a helicopter and it went 105 centimetres and the Group was 5* [ID155]).

To assist in determining if one seed dispersal model went further than the others, some students read the legend (e.g., *So the parachute is red. The blue one is a helicopter and the yellow one is sail.* [ID158]). Others read the axes, as illustrated in the following exchange between the interviewer (I) and the student (S):

> I: How did you know that is "helicopter"?
>
> S: Because it says down the bottom [along the horizontal axis]. [ID162]

Reading within the data: Understanding relationships among elements of graphs and the data. All 45 students interviewed were able to read within the data to compare the performance of the three seed dispersal models. Examples include students using the data to decide which model went the furthest (e.g., *Sail came first, then parachute second and helicopter third* [ID106]), or where most of the data were situated (e.g., *In the middle* [ID159]). The students also responded to questions on consistency and variation, using the data to inform their decision. For example:

> Maybe the sail [had the least consistency] because there's some down here, like the 60's and 70's, and there's some up here, but … there's a big gap there. [ID129]
>
> I think sail [has more variation]. Because, like, if you have a look at the helicopter that is still pretty far apart, but sail is more far apart. [ID139]

For some students, their comments illustrate the difficulty of reading within the data to make decisions. For example [ID110]:

> I: So, does that help you maybe decide which one you think was the best method?
>
> S: Probably the best method was parachute. They were all good methods, but parachute went the furthest, but at the same time it went the least furthest.
>
> [A few minutes later.]
>
> I: So now what would make you decide that one of those was better? What do you think?
>
> S: Helicopter probably because it is like in the middle-ish and then sails like back that way and then parachute is all spread out.

Similarly,

> So, the green one [sail] definitely is more consistently higher and parachute is just spread out and there's a lot of ones down here but at the same time most of the dots are further than the green. I think blue looks pretty good because there's so many up here. But I think red, parachute [is the best because of] the middle distance. [ID161]

Reading beyond the data: Interpreting information in the graph. Twenty-four students read beyond the data to interpret the information. Some used age-appropriate knowledge of seed dispersal and plant science to make decisions about the best method of dispersal. For example:

> I would probably say the helicopters [are the best] because it travelled more consistent and it wasn't close, but it wasn't far away. With this one [parachute] it could land anywhere, it could land in a bad spot or it could land in a very good spot, but you would have no idea. But this one [helicopter] you know it is going to land probably in a good spot and this one [sail] is probably not the best because it doesn't go as far. [ID101]
>
> [The parachute is best] because they spread out everywhere. And they're not bunched together in one spot where they can grow and this one they can grow further and spread out. [ID123]

Some students used the data to inform their decision on which model to make in the future. For example, ID127 would have chosen to make a parachute "because from the data most of the parachutes go further than the rest." Similarly, ID119 commented that she would "probably choose parachute because it also goes, like, the furthest." Others focused on the consistency of the models (e.g., *Maybe sail … so I can get a bit more consistency, so it doesn't go all over the place or it doesn't go too high or too low because it is mostly consistent* [ID149]), and some noted that the decision is dependent on whether the device was for the seed to travel as far as possible, or land consistently. For example:

> Again, depending on whether I wanted it to be consistent or go further away. Maybe the yellow ones, the sail ones. But if you wanted it to be more consistent I would probably go with the parachute ones. [ID113]

Reading behind the data: Looking for possible causes and implications of variation in the data. Sixty percent of the students used their memory of the activity to justify decisions about the data. For example, to explain the variation observed, ID136 commented, "I think Group 7 has got a very small amount of variation because they were probably, like, just kind of dropping it [in front of the fan]". She went on to explain that "helicopter probably didn't go as far because it is really hard to get the spin just right." Other examples include:

> So, these guys [sails] obviously maybe dropped it different to these groups [helicopters and parachutes]. Because these people [helicopters] may have dropped it kind of similar to each other and that's why they have got the same. These people [sails] obviously dropped it a bit more, you know, not like the same as each other. That's why they have got these distances. [ID155]

> Maybe because the parachute copped the wind and threw it further. [ID149]

Some, like ID136 above, commented on the impact on variation of the design of the seed dispersal device:

> It depends what kind of parachute it is. Like, they could have made, the lowest one could have made a really bad one and it has gone down [only a little way] and every [other] one has gone far. [ID109]

> Well, I guess it depends how you make it. [ID135]

> …only some of them are down the bottom [of the scale] because that's how they made it. [ID154]

> … these ones here, they probably used some of the same materials as each other. That's why they are all [together] and they probably look a bit the same because they are all around here and they went the same distance, nearly. [ID111]

Their memory of the activity also helped some students to justify their decision about which method is best. For example,

> …the reason I think Sail is the best is because you use paper for the sail and paper likes to fly around. [ID147]

> Probably the parachute. The sail might have gone further because it was easier to throw but then the helicopter, like, [you] had to make it spin and move at the same time. [ID119]

When choosing which model to design in the future, some students focussed on the materials:

> I think I have learnt that it depends how you make it. Like it depends what materials you do. Like polystyrene, it is pretty light, so it would float better. If you used some stones or something it could weight it down, so it wouldn't be as fast. I think you have to be pretty careful with what you do. Maybe you want to make it as light as possible, I think because it can float. Like a feather. Chuck it up and it takes a while to sink down to the ground. [ID155]

> I would probably choose the sail because the sail you can make sort of lightish. Where with the helicopter you sort of got to add bits and bobs to make it similar to what a normal helicopter seed would look like and the parachute to make it sort of like glide instead of just sink. [ID125]
>
> And helicopters sometimes they didn't move because they're too heavy. [ID141]

Another student, ID126, showed an appreciation of fair test conditions by suggesting everyone make the same type of device to "see which design was best for this particular seed."

Discussion and Conclusion

The research reported in this paper addresses the concern expressed by Rosicka (2016) that few studies report "on evidence-based practical applications, programs or interventions that can be implemented in the primary classroom to address STEM learning" (p. 4). It provides evidence of outcomes from taking an integrated approach to STEM learning through a focus on students working through the engineering design process (Ward et al., 2016) in tandem with the practice of statistics (Watson et al., 2018) to construct, trial, and improve a seed dispersal device (adapted from Pike, 2017). The engineering design process served as a pedagogical framework for directing the STEM investigation and the practice of statistics put the focus on using data to evaluate the performance of the seed dispersal devices, which included the original and modified devices.

The students in this study worked through the four stages of the practice of statistics described by Watson and her colleagues (2018) whilst also enacting the engineering design process in the construction and evaluation of seed dispersal devices (Ward et al., 2016). They demonstrated their capacity to collect, represent, and analyse the data, and make decisions about changes to devices based on their analyses. This put the use of data and subsequent analyses in the forefront of student decision-making in the Test and Evaluate phase of the engineering design process. Using the four categories of the Shaughnessy (2007) graph understanding framework to guide the student interviews aimed to draw out the connections students had made among the STEM disciplines associated with the learning activity.

Analysis of the graphical representations constructed by the students to show the distance travelled by the modified seed dispersal devices when launched in front of a fan revealed that the students chose a variety of graph types to display the data. Importantly, 89% of the students chose a representation that allowed them to compare directly the performance of the three types of devices: sails, helicopters, and parachutes. The capacity to do this was facilitated by using the educational data analysis software, *TinkerPlots* (Konold & Miller, 2015). Drawing a graph by hand to compare the performance of three different devices may have resulted in representations that did not exhibit the accuracy needed to make the comparison.

The other factor that supported such a large majority of students to be able to construct useful graphical representations was the sustained learning in graph construction and graph interpretation experienced as part of participating in the longitudinal study from which this report was taken (Fitzallen & Watson, in press; Watson, Fitzallen, English et al., 2019). The benefits of sustained learning that takes a developmental approach is well-documented in the educational research literature. Unfortunately, sustained STEM education learning experiences are not common place in schools (Rosicka, 2016).

Analysis of the interview transcripts revealed that all the students were able to read directly the details from the graphical representations to make comments about the relationships displayed by the graphs. However, connections to the more complex ideas of identifying the relationships among the data and making informal inferences that included the uncertainty evident in the data (Makar & Rubin, 2009) were made by fewer students.

When the students were asked about making potential changes to devices in the future, they started to make connections about the performance of the seed dispersal devices to their knowledge and understanding of content from the STEM disciplines. The students expressed ideas about flight, which is a Science concept, when they used terms like glide, float, and spin. In most of these instances the students related the terms to the ability of the devices to move and travel. Connections were made to Technology concepts when the students described the properties of the materials used to construct the devices. Some students were able to identify that the materials would affect the ability of the devices to move and travel. References to the design of the devices and how the different properties of the designs affected the way in which they caught the wind when launched demonstrated connections to Engineering concepts related to the performance and behaviour of a designed solution (ACARA, 2019).

Although this study illustrates the potential connections made by the students to the Science, Technology, and Engineering disciplines when the focus was on analysing and interpreting data, it did not explore the extent to which students understood the ideas expressed. It demonstrates, however, the benefit of including elements in data investigations that require students to go beyond the data collected for making connections to other disciplines. It appeared that when the students were required to justify decisions or make predictions or recommendations from the data, they related their ideas to the situation within which the data were collected. This provided the opportunity for students to demonstrate the connections they had made among the STEM disciplines. This research also adds weight to Rao's (1975) assertion that an interdisciplinary approach to learning suits the teaching of statistics.

Taking advantage of the opportunities for learning in all the STEM disciplines when implementing activities like designing and trialling a wind dispersal device poses many challenges. The seed dispersal activity focused on the M and E of the STEM acronym. It did not focus on the potential learning outcomes for the T and the S. Had it done so, it would have been possible to explore and extend student understanding of the additional concepts of flight and the properties of materials they identified in the interviews. This implies that outcomes for all the potential STEM outcomes need to be considered when planning integrated learning activities, whether they be for research or enactment in the classroom. Adopting this view would assist in making STEM learning more purposeful and less incidental than currently implied when research set within STEM contexts only report on outcomes for one of the disciplines. Planning approaches such as *Understanding by Design* (Wiggins & McTighe, 2011) that identify desired learning outcomes before choosing the learning activities to implement may assist in developing holistic integrated learning activities. This is not to suggest all four disciplines need to be incorporated in every activity. Rather, it promotes the view that integration of learning comes from purposeful and meaningful use of the ideas and concepts associated with the context of the situation chosen (Fraser et al., 2019). An increased research focus on ways in which planning frameworks can support teachers' skills in implementing STEM integrated learning would be beneficial.

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RESEARCH REPORT

"Can We Build the Wind Powered Car Again?" Students' and Teachers' Responses to a New Integrated STEM Curriculum

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Abstract: *Recently, STEM (science, technology, engineering and mathematics) education has become a focus in the Australian context, particularly since the release of government-initiated reports into Australia's falling performance on international tests and fewer enrolments in senior school STEM subjects and university STEM degrees. Since student engagement in STEM subjects begins to decline in primary school (Kindergarten to grade 6 in Australia [5-12 years of age]), addressing engagement and achievement in the STEM subjects requires support for teachers to design curriculum that enthuses students and develops their understanding of the role of the STEM subjects in solving real-world problems. To that end, a year-long professional learning program was developed to assist small teams of teachers from each of 13 primary schools in designing integrated STEM curriculum approaches. To determine the impact of the program on teachers' capacity to design integrated STEM curriculum and on students' STEM attitudes and aspirations, data were collected using both qualitative and quantitative research methods. This paper presents a case study of one of the participating primary schools. From the 44 grade 3 students who completed both pre- and post-surveys, students' attitudes and aspirations towards the STEM subjects showed significant positive shifts. Analyses of school documents and transcripts of interviews with four teachers and a group of four students from the school enabled.*

Keywords: Integrated STEM curriculum; Professional development; tudent attitudes and aspirations; School collaborative teams

Introduction

While STEM education has had international attention for some time (e.g., Bybee, 2013; Honey, Pearson, & Schweingruber, 2014), it had limited attention in Australia until the release of a series of reports from the Office of the Chief Scientist (2014; 2016a; 2017), reports of continuing decline of students' results on TIMSS and PISA international assessment programs (e.g., Thomson, Wernert, O'Grady, & Rodrigues, 2016), and an Australian Federal Government push to build the economy through innovation and creativity, starting with inspiring entrepreneurship in schools (Commonwealth of Australia, 2017). These reports have been accompanied by a burgeoning landscape of programs for teachers and students (Office of the Chief Scientist, 2016b) including outreach programs from universities (e.g., Robogals, https://robogals.org/), professional learning offerings for teachers (e.g., Microsoft Schools Programs, https://education.microsoft.com/microsoft-schools-overview) and an increased focus on updating the curriculum, particularly for science and technology in the primary school grades (Kindergarten to grade 6 [5-12 years of age]). In 2015, the Federal government recognised that much of this activity was disparate and uncoordinated, so a forum was

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held with a range of stakeholders to develop a *National STEM School Education Strategy* (National Council, 2015) with two clear goals, five areas for national action, and seven guiding principles for schools to support STEM education. The report recognised the importance of improving learning and teaching in the separate STEM subjects as well as considering ways to connect and integrate the subjects in meaningful ways.

To address teachers' knowledge, beliefs and practices in the STEM school education context, a new professional learning program was developed at the authors' institution in 2014, the *STEM Teacher Enrichment Academy*. Based on high-quality, high-impact professional development design principles (Borko, Jacobs, & Koellner, 2010; Darling-Hammond, Hyler, Gardner, & Espinoza, 2017; Desimone, 2009), the *Academy* program involved teams of teachers from each participating school, working collaboratively to create tasks, lessons and units of work (Voogt, Pieters, & Handelzalts, 2016) involving real-world STEM problems emphasizing creativity and critical thinking (Freeman, Marginson, & Tytler, 2015).

The Academy was initially developed for teams of STEM teachers from secondary schools (grades 7 to 12 [13-18 years of age]) with each school sending two mathematics, two science and two technology teachers to develop a STEM program addressing a school-identified need (Anderson, Holmes, Tully, & Williams, 2017). Secondary school contexts are more complex than primary schools because of the challenges of working across discipline-based departments to develop integrated STEM curriculum, and because mathematics and science are not compulsory in grades 11 and 12 in Australia students are choosing to opt out at the earliest opportunity (Tytler, Williams, Hobbs, & Anderson, 2019).

Based on the success of the program in secondary schools (Anderson et al., 2017), a new program was developed in 2017 to work with primary schools in a large regional town in Australia. Thirteen schools participated in the inaugural primary program with each sending between one (very small schools) to four teachers to work with a team of academics to develop an integrated STEM approach for their students. The Academy program began with a two-day introduction to integrated curriculum and STEM practices, providing time for school teams to design projects for implementation with their students over the following five months. This was followed by a further two-day sharing and planning session in the middle of the school year before a final showcase at the end of the year. Between face-to-face sessions, an important component of the Academy program involved an experienced local school leader who mentored schools by visiting on at least two occasions to attend meetings and to provide feedback and advice on their approach and STEM curriculum design ideas.

This paper examines the research about the potential impact of integrated STEM education for primary school students, and presents characteristics identified in the literature of effective integrated STEM education approaches. This is followed by the methodology, the data and findings from one of the primary schools, inferences about the characteristics of the integrated STEM program that appear to have influenced the positive student outcomes and suggestions for further research.

The research questions to be addressed in this paper include:

1. After the 12-month STEM Academy program, what changes were evident in students' attitudes and aspirations towards STEM?
2. How did the case study school change the development and delivery of the STEM curriculum in their school during 2017?
3. Based on analyses of school documents and interviews with teachers and students, which of the proposed characteristics of effective integrated STEM programs appear to have influenced students' attitudes and aspirations?

Research about Integrated STEM Education for Primary School Students

Research into the efficacy of integrated STEM education in primary schools, particularly regarding long-term benefits to students, is still an emerging field. However, evidence is gradually building that an integrated, interdisciplinary approach to teaching science, technology and mathematics (including engineering-like design practices) has some benefits as it supports improved problem-solving skills, increased learning-engagement and improved science and mathematics outcomes (Becker & Park, 2011; Tytler et al., 2019). One of the challenges in designing STEM curriculum for primary school students is striking the balance between developing the knowledge and skills of each of the separate STEM subjects and designing learning experiences where students can choose to use and apply their knowledge from any of the STEM subjects to solve new and unfamiliar problems (Hobbs, Cripps Clark, & Plant, 2018). As cautioned by Graven (2016, p. 8), subject integration may create problems in subjects like mathematics where "progression is structurally important." Hence, the Academy program encourages teachers to complement their mathematics program with integrated STEM learning experiences – we argue both are important in the primary school curriculum.

While engineering, as a subject, is not part of the Australian Curriculum for primary education, engineering design processes (such as problem scoping, idea generation, design and construction, design evaluation, redesign) are embedded in the science and technology curriculum (New South .Wales Education Standards Authority, 2017). Such a design process is becoming a common feature in integrated STEM projects, with research suggesting the importance of the final two phases of "design evaluation" and "redesign" in promoting learning in mathematics and science (English & King, 2015).

Combining inquiry-based learning with an integrated STEM approach provides rich opportunities for students to develop a range of general capabilities such as critical thinking, self-direction, creativity and communication (Rosicka, 2016). Inquiry approaches require active learning by the students, and place emphasis on intrinsic motivation to seek knowledge and solutions, and on developing the skills needed for seeking, organizing, evaluating and applying the knowledge believed to be essential for creating the desired solution. When the inquiry focuses on a real-world problem that is meaningful to the students, their engagement has been found to extend beyond their immediate learning, to increased interest in further study in the component disciplines of STEM, and in future STEM related careers (Holmes, Gore, Smith, & Lloyd, 2018). Future aspirations for STEM may be enhanced by explicit conversations about careers, excursions into the community (Rosicka, 2016), and contact with actual STEM professionals (Tomas, Jackson, & Carlisle, 2014). Attending to the attitudinal outcomes of STEM programs is particularly important for addressing equity issues faced by portions of the student population who would not have otherwise considered STEM pathways. Building confidence in STEM inquiry capabilities and expanding awareness of STEM careers has been found to be particularly beneficial to girls, and students from families who do not have any connections to STEM professionals (Holmes et al., 2018).

The following section reviews the literature into the potential characteristics of effective integrated STEM education, highlights the issues for teachers when designing integrated teaching and learning experiences, and builds a case for the need to better understand how such characteristics might contribute to improving teachers' capacity to design integrated STEM curriculum and to improving students' attitudes and aspirations.

Potential Characteristics of Effective Integrated STEM Education Approaches

Common features of integrated STEM education definitions suggest a student-centred, project-based collaborative approach where students identify real-world problems and apply prior learning from science, technology and mathematics to design and create solutions (Bybee, 2013; English, 2017; Honey & Kanter, 2013) and generate innovative ideas that transcend the individual disciplines

(Barron & Darling-Hammond, 2008; Roehrig, Moore, Wang, & Park, 2012). To create these types of learning experiences for students requires substantial work from teachers and school leaders. The characteristics identified in the literature as supporting this work include the level of curriculum integration, the type of inquiry-based learning, teacher capacity, school culture, the use of STEM role models, and connections among the school and local communities. These characteristics were considered in the design of the Academy program and used to inform the design of the case study research reported in this paper. Although each characteristic is discussed separately in this section, we acknowledge they are connected.

Level of Curriculum Integration

Some researchers discuss a continuum of integration of the STEM subjects from segregated at one end to integrated at the other (e.g., Vasquez, 2015), with ideal involving a "seamless amalgamation of content and concepts" so that "knowledge and process of the specific STEM disciplines are considered simultaneously without regard for the discipline, but rather in the context of a problem, project or task" (Nadelson & Seifert, 2017, p. 221). So, the level of integration of the adopted approach should be considered when determining whether there is genuine curriculum integration and that it is intentional, planned and purposeful. Vasquez' (2015, p. 13) "inclined plane of STEM integration" provides one model to inform the research (Figure 1). We acknowledge there are other models which are less hierarchical (e.g., Rennie, Venville, & Wallace, 2018) as they describe the different types of approaches such as thematic, project based, and school specialised, among others. We believe, however, this simplified model serves the purpose of engaging teachers with an evolving process of building connections from simple subject-based connections to more complex transdisciplinary projects without specific reference to the separate subjects.

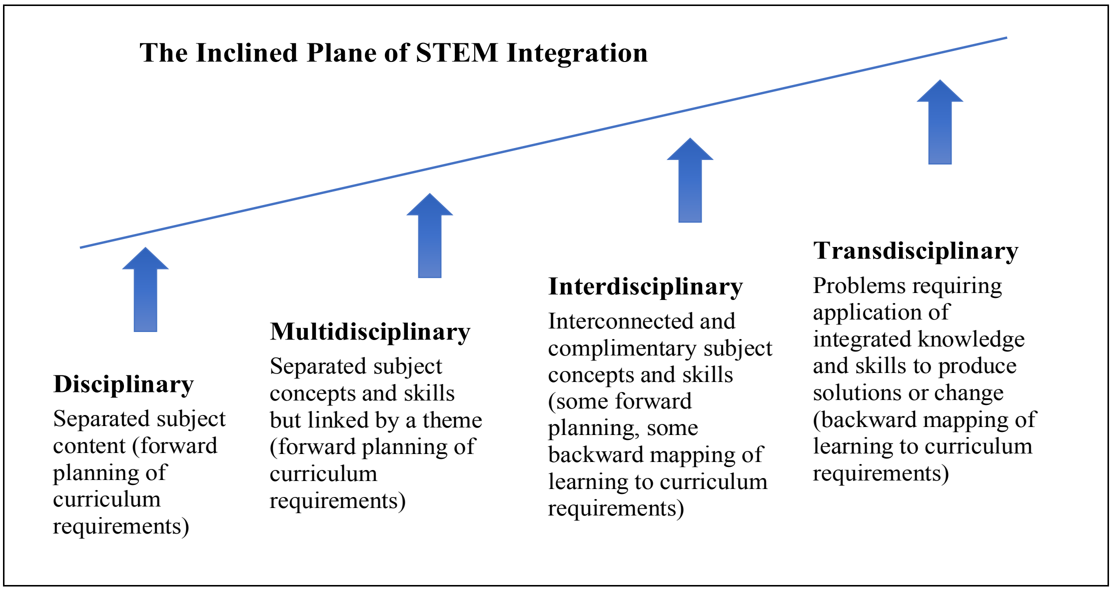
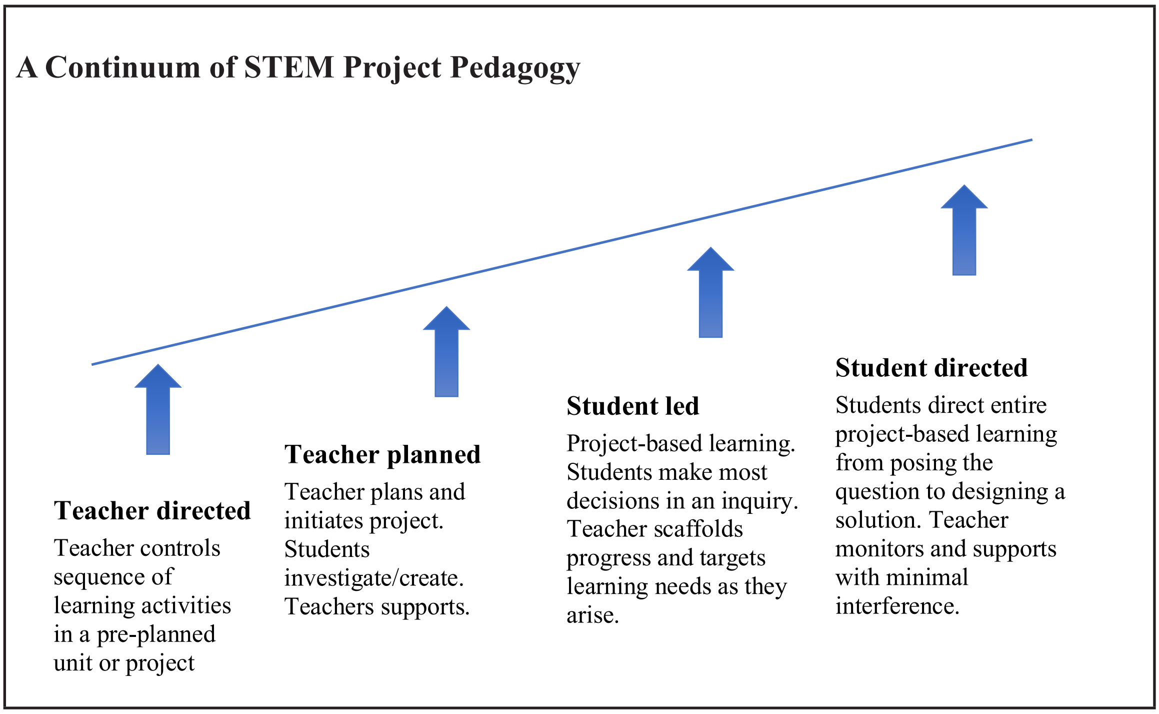


Figure 1. A continuum of STEM integration adapted from Vasquez (2015, p. 13).

Issues for teachers when designing integrated STEM approaches include subject imbalance in STEM project work and maintaining the integrity of the separate subjects (Honey et al., 2014). Some suggest students must learn the concepts of the subjects before they can apply them in an integrated context (e.g., Nadelson & Seifert, 2017). Others suggest content and skills can be learnt through integrated STEM projects (e.g., Tytler et al., 2019). These are important considerations and it is critical that teachers make such decisions about whether their students need to learn the skills first before applying them to new situations. Whichever approach teachers choose to use, mapping curriculum requirements either before or after students complete projects is an important component of teachers' work. English, King and Smeed (2017) argue for a greater focus on STEM integration, but with a more equitable representation of the four subjects, which can be challenging for teachers to achieve (Tytler, Symington, & Smith, 2011). Finally, integrating curriculum requires a "shift in the philosophical framework for teaching and learning" and hence, extensive change in pedagogy (Myers & Berkowicz, 2015, p. 25).

The Type of Inquiry-based Learning

Developing effective pedagogical practices that encourage students to pose their own questions is strongly recommended (e.g., Honey & Kanter, 2013; Newhause, 2017). This level of open inquiry is not easy for teachers as they need to allow students to take control of their learning and drive the investigation (Makar, 2007). Like the continuum of STEM integration, there is potentially a continuum of STEM project pedagogy that begins with greater teacher direction and ends with a higher level of student direction (see Figure 2).



A Continuum of STEM Project Pedagogy

Teacher directed
Teacher controls sequence of learning activities in a pre-planned unit or project

Teacher planned
Teacher plans and initiates project. Students investigate/create. Teachers supports.

Student led
Project-based learning. Students make most decisions in an inquiry. Teacher scaffolds progress and targets learning needs as they arise.

Student directed
Students direct entire project-based learning from posing the question to designing a solution. Teacher monitors and supports with minimal interference.

Figure 2. A continuum of STEM project pedagogy

Again, we acknowledge this is a simplified model but it is a useful tool to illicit teacher conversations about the level of teacher support required as students learn to become independent problem solvers. For some teachers, beginning with a more structured inquiry helps to prepare both teachers and students to develop the other important skills needed for inquiry-based learning, including collaboration (Anderson, 2016). If students are not familiar with working with peers on open-ended inquiry projects, time needs to be spent on developing appropriate social norms and practices such as positive interdependence, promotive interaction, and mutual accountability (Gillies, 2007, 2016). This can take time but can be managed if teachers are provided with support and mentoring.

Teacher Capacity

Critical to developing integrated STEM education programs in schools is appropriate and sustained professional learning that targets teachers' understanding of approaches to designing integrated STEM curriculum; develops their understanding of, and capacity to deliver, effective pedagogical practices; provides mentoring and ongoing support as they design and trial STEM tasks, lessons and units of work; and supports collaboration between teachers (Darling-Hammond et al., 2017). The STEM Academy was designed specifically to address the identified features of effective professional learning incorporating the support from an external mentor (Anderson & Tully, in press). However, developing teacher capacity is a long-term goal in all schools and needs to be strongly supported within the school community (Bryk & Snyder, 2003) and within a supportive school culture.

School Culture

Principals and school leaders are key drivers of successful change in schools and for introducing integrated STEM curriculum for the first time. Their roles include garnering support for STEM within the school and in the broader community (Prinsley & Johntson, 2015), and harnessing the expertise of staff while developing a school culture of sharing and learning together. They have the potential to create a school culture that facilitates individual and collective teacher efficacy (Nadelson et al., 2013). Teacher efficacy in STEM influences student attitudes towards STEM and aspirations towards a STEM related career (Maltese & Tai, 2011). Collective teacher efficacy promotes teacher confidence and enhances competence in teaching STEM, ultimately impacting student learning. Bolman and Deal (2017) suggest that change can only be achieved and sustained within a framework that includes supportive leadership and a positive school climate that recognises teachers' disparate needs and capacities. Teachers need to feel trusted to try new ways of working and respected for their work and expertise. In addition, another important characteristic of developing an effective integrated STEM program that enhances students' STEM aspirations is knowing about potential STEM career pathways and understanding the ways STEM practices can be used to solve real-world problems.

STEM Role Models

One way to develop students' STEM aspirations is to use community-based role models to develop students' understandings of how STEM can be used in productive ways to solve real-world problems. This can be achieved by using videos of scientists talking about their work (Wyss, Heulskamp, & Siebert, 2012), by inviting guest speakers to visit the school, by working with a STEM professional as a mentor for teachers to develop their knowledge and understanding, for example, The STEM Professionals in Schools Program implemented in Australia by the CSIRO (Commonwealth Scientific and Industrial Research Organisation) (Tytler et al., 2015), or by connecting with members of the local community including industry groups (Hobbs et al., 2018). Allowing students to interact with STEM professionals has the capacity to break down barriers, address misconceptions, and encourage students from a young age to consider STEM pathways as potential opportunities for future careers and aspirations, particularly for girls (Leaper, 2015; Shapiro & Williams, 2012). If the role models are from the local community, this may open possibilities for increased community engagement and support for a school's STEM program.

Community Engagement

Community and industry partnerships provide the opportunity for students to understand how the STEM field contributes to society and to recognise the benefits of engaging in a STEM career. For some, engineering design is a pivotal factor for effective STEM integration, facilitating the merging of the central concepts inherent in science, technology and mathematics as it has the potential to mirror the work of the STEM workplace (Tytler, Symington, Williams, & White, 2017). Several studies have demonstrated that primary school students can successfully engage in engineering design projects (e.g., English & King, 2015). For example, when designing wind-powered cars, students can learn about forces in science, they can learn about measuring speed in mathematics, and they can learn about the use of appropriate materials in technology and engineering. It is through the design process that students' knowledge and understanding of key subject-based concepts can be applied and refined with the careful guidance of the teacher.

Local businesses and industries may be willing to send representatives to visit schools to talk with teachers and students, or have teachers and students visit a local site of interest (Office of the Chief Scientist, 2017). From our experience with the STEM Academy, many organisations are keen to partner with schools to raise student awareness of local issues and other real-world problems. For example, one school had students visit a local recycling depot to learn about how the school might improve the recycling of their waste materials.

Proposed Model of an Effective Integrated STEM Education Program

Several rubrics and frameworks have been developed to support teachers' work in designing integrated STEM programs. For example, the New York State STEM Quality Learning Rubric (https://www.stemx.us/resources/) but such frameworks rarely refer to published research. Our review of the literature proposes a set of six potential characteristics for successful STEM curriculum integration (Table 1).

Table 1. *Key Characteristics of STEM Integrated Programs*

Key Characteristics	**Possible Progressions:**	**Rationale**	**Expected outcomes**
Curriculum integration: Intentional, planned, purposeful	Connections between 1. multidisciplinary 2. interdisciplinary 3. transdisciplinary	Students will see more relevance, gain greater understanding and enjoyment in learning STEM subjects	Increased engagement Increased capacity to apply learning in novel contexts 21st century skillset
Inquiry-based learning: Hands-on Collaborative Student centred	1. Teacher planned 2. Student led 3. Student directed	Students learn to apply skills and competencies of STEM subjects to real world issues in collaboration with peers and in an authentic context, or they learn new concepts and skills	Students gain a deeper understanding of key concepts Students take responsibility for their own learning
Teacher Capacity: Reflective practice, Developing understanding of integrated STEM, Continuous PD	1. Little understanding of STEM integration 2. Emerging knowledge 3. Sound knowledge and understanding	As teachers feel more confident and enthusiastic, they will have a greater impact on student outcomes	Teachers will develop knowledge and confidence in STEM delivery
School culture: Community, school and district share a belief in the program	1. Small group interest 2. Executive and parent support 3. Community and school in joint venture	The support of the school and the community will facilitate the development and continuation of exemplary STEM programs	Students will perceive STEM as a valued and worthwhile venture
Role models: Diverse Appropriate Mirror potential	1. Videos of STEM role models 2. Visits from STEM professional 3. Mentoring by appropriate community	Students develop understanding of the role of STEM and develop aspirations to follow STEM pathways	Reduced stereotypes Perceived similarity to people in STEM jobs Increased self-efficacy in STEM subjects
Connection with community: Use school demographic data Continuous support	1. Visiting specialists 2. Excursions to local organisations 3. Joint enterprise between class/school and local organisation	Students will gain knowledge about the variety of STEM jobs and their potential positive social impact	Increased sense of identity with STEM careers Increased aspirations towards a career in STEM related industry

Because the six characteristicsof STEM integrated programs identified are interconnected, it seems more appropriate to propose a connected model that includes guiding questions for teachers. We propose effective integrated STEM curriculum programs in schools require consideration of each of these characteristics in the design and development of programs that have the goal of changing students' STEM attitudes and aspirations (see Figure 3).

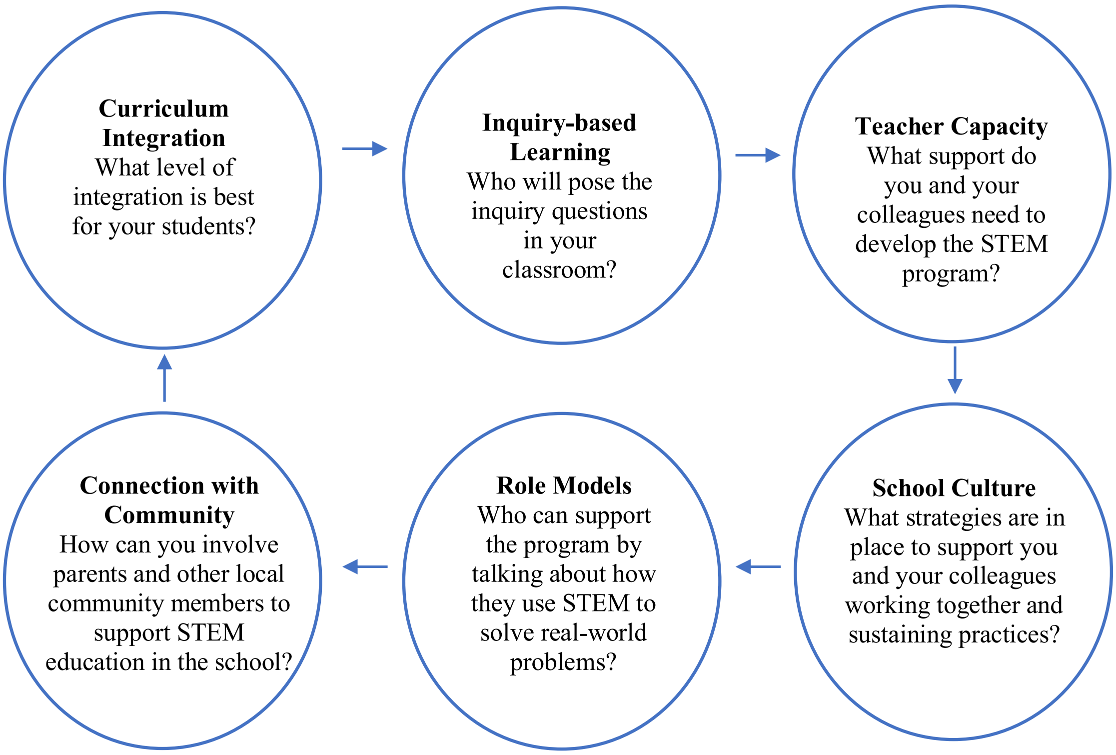


Figure 3. Proposed model of key characteristics of an effective integrated STEM program.

Even though the model proposed in Figure 3 has been informed by research and recommendations from a range of sources, it needs to be tested in practice to determine whether these characteristics have the potential to inform the development of a school-based STEM programs. In a study where students' attitudes and aspirations improved after a year-long professional learning program for their teachers, the set of six characteristics was used to determine which of the characteristics led to improved student attitudes and aspirations towards a career in STEM. This paper reports the findings of that investigation in one primary school.

The Methodology

The key characteristics from Table 1 and Figure 3 and the Academy program objectives informed the overall methodology and development of instruments for the research reported in this paper. Using a mixed methods approach (Creswell & Plano Clark, 2018) that incorporated an instrumental case study (Stake, 1995), analyses of student survey responses, a range of school documents, and interview transcripts were used to measure outcomes for school STEM leaders, teachers and students. Although parent and industry partners are also important stakeholders in integrated STEM approaches in schools, because of limited time and access, we did not collect data from either of these stakeholders for this paper.

Data Collection

Embedded within the survey developed for this study were three STEM attitudinal factors taken from the *Hopes and Goals Survey for use in STEM Elementary Education* (Douglas & Strobel, 2015) measuring student attitudes in mathematics, science and engineering, as well as future career interest. This validated instrument contains five factors and was constructed with a focus on STEM attitudes and aspirations for primary students in grades 3 to 5. Exploratory factor analysis (n=265) and confirmatory factor analysis (n=193) were undertaken by Douglas and Strobel (2015) in the development of their instrument with data collected from children attending urban primary schools. Results suggest that the Hopes and Goals Survey is a five-factor model with internal consistency ranging from 0.609 to 0.904. An additional validity and reliability study of the Hopes and Goals survey was recently undertaken by Yaman, Tungaç, & İncebacak (2019) with 873 students. These researchers utilised exploratory factor analysis and confirmatory factor analysis to evaluate the factor structure of the instrument and the appropriateness of its structure. Their confirmatory factor analysis fit indices confirms the factors used in this study. Of the five factors within the Hopes and Goals survey, the three attitudinal factors were specifically selected for use in this study.

The survey used for this study was adapted from the original Douglas and Strobel (2015) instrument with the specific factor of *Attitude Towards Engineering* changed to *Attitude Towards Technology* to more adequately reflect a focus on design and technology, as in the current curriculum documents. It comprised 14 items with a five-point Likert-scale of 1 to 5 (1: strongly disagree [SD] to 5: strongly agree [SA]) – the first 11 items relate specifically to attitudes and aspirations to STEM. A final set of questions asked students to name their favourite subject at school, their current year level, the name of their school, and their gender. Student surveys were administered by teachers both pre- and post-program allowing for matching and comparison through repeated measures statistical testing.

Even though the overall Academy program for primary schools in 2017 involved 13 schools and more than 45 teachers, we have chosen to report the findings from one case-study school in this paper, Crowdon Primary School (a pseudonym). Crowdon Primary School was chosen as it had characteristics that distinguished it from the other 12 schools in the Academy, including:

- there were no changes of teacher participants throughout the 12 months of the Academy program;
- it was one of the largest schools in the program with two classes of students participating in the STEM program in the school;
- most student participants completed both pre- and post-surveys;
- whereas some teachers had implemented project-based learning, the school was keen to implement STEM approaches across the whole school; and
- the Principal wanted to build more community connections into the school's program.

Our reason for reporting on one school is that case study research is a valid form of empirical inquiry that investigates and illuminates the findings of survey data (Yin, 2011). Although survey data may reveal "what" the sample thinks or believes and to what extent, the case study tells "how" and "why" participants think that way (Yin, 2002). A case study can give voice to individuals within a bounded system (Stake, 1995), providing rich detail about the context, the contraints and possibilities that the particular context offers. In our research, the context offered through an individual school setting defines the boundary lines for our case study.

To determine the impact of the Academy program within the case-study school, documents were collected, and interview protocols were designed for a range of participants including teachers and students. The first two authors visited the school during 2018 to collect information about the school's integrated STEM program and to interview members of the STEM Academy team, which included the STEM leader, the school's librarian, and the two teachers of grade 3. We also interviewed a group of four students (three females and one male, 8 years of age) from grade 3 who were the target for the school's STEM program—these students were chosen by the STEM team for interview on the basis of their engagement with and interest in the STEM projects completed by the two grade 3 classes during 2017. We did not interview the Principal as he had moved to another school at the end of 2017.

Data Analysis

The school provided a large set of materials as evidence of their work throughout the year. After scanning the full set of materials, many of which contained similar information, the first two researchers selected the following documents for analysis as they provided a comprehensive picture of the school's STEM journey throughout 2018:

- the Expression of Interest submitted by the school to join the STEM Academy;
- the Early Draft Plan completed after the first two days of the Academy program in February 2017;
- the Progress Report presented at the STEM Academy meeting in June 2017;
- the Final Presentation slides delivered at the Academy showcase event in November;
- the Final School Report submitted at the end of the STEM Academy program in November 2017;
- the school's Program for grade 3 outlining each of the specific STEM projects implemented during 2017; and
- a small number of student work samples and photographs of students' projects.

The documents were analysed independently by the first two authors and coded for characteristics that might have influenced students' interest and aspirations in STEM. Our findings were compared to identify similarities and differences. After extensive discussions, we agreed on a set of characteristics for further investigation through responses to the interview questions. This process led to the identification of a final set of characteristics evident in this school's integrated STEM program, but before presenting the data and results, we provide further background information about the school.

The School

The case-study school, Crowdon Primary School, is a Catholic co-educational primary school in a large regional town in Australia and includes students from Kindergarten to grade 6 (ages 5 – 12). In 2017, the school had a student population of 402 (199 boys, 203 girls) students with 28 full and part-time teachers and nine support staff. After 28 years of development, Crowdon Primary School had grown to two classes in each grade level, with students performing above average compared to a set of like (or matched) schools, based on size, location, socio-economic status and other demographic factors, and in national literacy and numeracy assessment tests (https://www.myschool.edu.au/). With a parent body from higher than average socio-economic backgrounds, the school community was supportive of teachers' efforts.

For participation in the STEM Academy professional learning program in 2017, the school sent a team of four school personnel. This included the STEM leader, who was the school's Information Technology teacher with responsibility to support staff members in implementing technology across the school (henceforth referred to as "STEM Leader").The school team also included a teacher librarian with a keen interest in mathematics, science and project-based learning and who had an additional role in the school of supporting teachers to implement project-based learning (Librarian)—she typically did this by team teaching with the less experienced teachers. The final two members of the school's STEM team were the two teachers of grade 3 (Chris and Jazz, pseudonyms). In the next section, we report the findings from the student surveys followed by data collected through document analyses and interviews.

Results and Discussion

The mixed-methods approach enabled collection of data from several sources to identify the changes in students' STEM attitudes and aspirations, the changes in development and delivery of STEM curriculum during 2017, and characteristics of the school developed integrated STEM program that appeared to have influenced students' changed attitudes and aspirations.

Changes in Students' STEM Attitudes and Aspirations

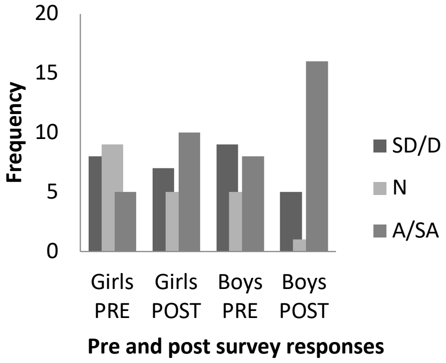
Using the data from Crowdon Primary School, we sought to discover if there was any change in student attitudes and STEM aspirations since experiencing integrated STEM teaching and learning for the first time. Forty-four students from grade 3 (out of a cohort of 52 students giving a response rate of 85%) completed both the pre-and post-surveys. Students used an identifier code so that surveys could be matched. Wilcoxon signed rank tests were applied to measure the change in individual student responses. For this school, students' attitudes towards science and attitudes towards technology showed significant results with a medium effect size, indicating meaningful positive shifts in students' attitudes and aspirations within these STEM domains. Additionally, comparisons between students' pre- and post-responses yielded statistically significant results in several of the attitude scales sub-items (see Table 2).

Table 2. *Comparison of Student STEM Attitude Indicators Using Wilcoxon Signed Rank Tests (N=44)*

	Pre-test Mdn	**Post-test Mdn**	***Z***	***p***	**r (effect size)**	**95% CI [LL, UL]**
Attitude Towards Science Scale [a] (pre α= .825; post α=.860)	15	16	-1.909	.056	.29	[0.00, 2.00]
I would be excited to have a job in science	3.0	4.0	-0.856	.392	.13	[0.00, 1.00]
Learning science is exciting	4.1	5.0	-1.330	.184	.20	[0.00, 0.00]
I feel good about learning science	4.0	4.0	-1.277	.202	.19	[0.00, 0.50]
It would be exciting to be a scientist	3.0	4.0	-2.146	.032*	.32	[0.00, 1.00]
Attitude Towards Technology Scale[a] (pre α=.726; post α =.804)	17	18	-1.733	.083	.26	[0.00, 2.00]
I feel good about learning with technology	5.0	5.0	-0.020	.984	-	[0.00, 0.00]
Learning with technology is exciting	5.0	5.0	-0.218	.827	-	[0.00, 0.00]
It would be exciting to have a job in technology	3.0	4.0	-1.837	.066	.28	[0.00, 0.50]
I am able to do well using technology	4.0	4.0	-2.872	.004**	.43	[0.00, 1.00]
Attitude Towards Maths Scale[b] (pre α=.877; post α =.797)	11	11.5	-1.644	.100	.25	[0.00. 2.00]
I feel good about learning maths	4.0	4.0	-1.294	.196	.20	[0.00, 0.00]
I am able to do well in maths	4.0	4.0	-0.160	.873	-	[-0.50, 0.00]
It would be exciting to have a job working with maths	3.0	3.0	-2.397	.017*	.36	[0.00, 1.00]

Notes: a. Science and Technology Scales: 4-20; b. Maths Scale: 3-15; Effect size (r=Z/sqrt n): small=.1; medium=.3; large=.5; 95% CI based on median differences using bootstrapping, *LL* and *UL* indicate lower and upper limits of confidence interval; **P*<.05; ***P*<.01

In drawing comparisons between pre- and post-surveys, individual student responses to almost all prompts indicated a positive increase in students' STEM specific attitudes. The career-based prompts of "It would be exciting to be a scientist" and "It would be exciting to have a job working with maths" yielded statistically significant results. A positive shift in aspirational attitudes was noted as the number of students who agreed with these statements doubled when comparing pre- and post-survey results (see Figures 4 and 5).



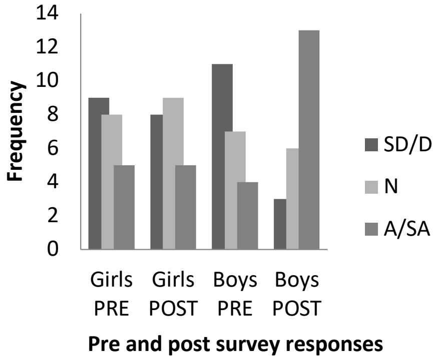


Figure 4. Students' responses to the prompt "it would be exciting to be a scientist" from strongly disagree [SD] to strongly agree [SA]

Figure 5. Students' responses to "it would be exciting to have a job working with maths" from strongly disagree [SD] to strongly agree [SA]

After engaging with an integrated STEM curriculum, the students in this school indicated positive growth in their self-efficacy within their self-reported use of technology (Z=2.872, p=.004, r=.43) (see Figure 6). Figures 4 to 6 present data for boys (n=22) and girls (n=22).

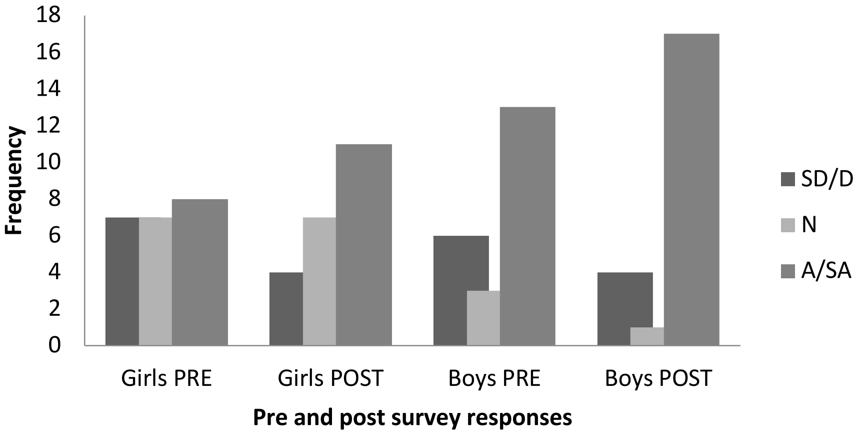


Figure 6. Students' responses to "it would be exciting to have a job working with technology" from strongly disagree [SD] to strongly agree [SA]

These results indicate significant positive shifts, particularly for the items related to career aspirations with boys reporting greater change than girls on each of these items. The results from this case study are encouraging as attitudes students possess towards STEM are a significant factor in influencing not only students' future STEM subject choice but also students' pursuit of STEM related careers (Maltese & Tai, 2011). To explore the reasons for these shifts and to determine which characteristics of the integrated STEM program might have had greatest impact, we examined school documents and interviewed teachers and students.

Changes in Development and Delivery of STEM in 2017

Prior to the STEM Teacher Enrichment Academy program, there was little implementation of integrated STEM in the school. While some classes participated in projects and inquiry-based learning, according to the Librarian, "this has been an isolated approach and hasn't supported students making connections to their learning and the wider world." Also, both grade 3 classes were taught science and technology by Chris, and both classes were taught HSIE (Human Society and its Environment, which includes history and geography) by Jazz; an approach not conducive to integrating science with the other STEM subjects. Chris and Jazz each taught mathematics to their own classes. STEM Leader noted

> whilst teachers are catering to the students' needs and meeting curriculum requirements, teachers had identified that they don't have the knowledge and resources to effectively implement the STEM initiatives to their full potential.

Librarian expressed some frustration that efforts before 2017 lacked purpose and connection to students

> Before the Academy, as a teacher librarian, I was trying to support teachers in inquiry-based units because that's my skill of leading [teachers] on how to research and how to inspire them. Before that there was little bits being done, but not anything with a purpose and I wasn't really fitting in to make it click with the kids why we need to learn [particular parts of the curriculum]. It was just a little like a topic pulled out.

Each of the grade 3 teachers was aware of the potential benefits of curriculum integration and student inquiry-based learning but expressed concerns about the need for curriculum coverage and the time taken for students to learn using inquiry approaches. Chris noted he did try to do some project work and to combine content but "we get so rigid and caught up in this is a subject I've got to teach now and how am I going to do that." Jazz was keen to use local issues in her lessons and to connect the content to students lived experiences but also commented on "a busy overcrowded curriculum" and "by the time we cover the content it's really hard to have any time left … to take it that step further and actually get them using the knowledge and applying it."

These comments suggest that at Crowdon Primary School there had been no intentional, purposeful or planned curriculum integration approach, particularly for the STEM subjects. There had been some efforts to implement inquiry-based learning. Yet it was disparate and disconnected, possibly impacted by limited teacher capacity and a tension between curriculum coverage and taking the time to make connections between learning the content in the curriculum and connecting to students' experiences. This was recognised by STEM Leader and Librarian as well as the Principal who helped to write the school's Expression of Interest to join the STEM Academy program. The Expression of Interest indicated the school was keen to

> … provide a cross disciplinary approach that will develop critical and creative thinking skills with an authentic context, problem solving and use of digital technologies, to equip our students to be lifelong and life wide learners. The interdisciplinary approach we would like to trial in 2017 allows educators to provide rich and authentic learning experiences, grounded in inquiry-based learning, which increases student engagement, leading to improved student knowledge and skills, to equip them for the future.

At the case-study school, the specific STEM projects designed and implemented by grade 3 teachers during 2017 included the design of a wind powered car during Term 1 (February/March), a water vessel powered by a small robotic sphere called a Sphero during Term 2 (May/June), and a portable container to grow lettuce from seedling to harvest during Term 3 (August/September). In addition, Jazz had students design and make scale models of pop-up shops to be located on the beach area in the centre of town, which was prone to flooding, during Term 4 (October/November). The last project also connected with the history and geography of the town with students exploring the history of flooding, and local landforms, before developing their designs to ensure ease of removal of the pop-up shop if flooding were to occur again. Input was provided by representatives from the local Council with students presenting their designs for critical feedback. These projects were designed to incorporate more than the STEM subjects to reflect the local issue of flooding in the town, and to help students learn the design process and develop their skills of working collaboratively.

Characteristics of the School Developed Integrated STEM Program

The final set of characteristics determined by data analyses indicated evidence of the early stages of curriculum integration, inquiry-based learning designed and led by teachers, emerging knowledge of STEM by teachers, and developing support from some sections of the school and local communities. Each of these will be discussed and supported by evidence from documents and interviews. While there was evidence of change and a commitment to embed integrated STEM in school programs and student experiences, many challenges were identified, which highlight the difficulty for teachers to move from already established practices to new and innovative ways of working.

Early stages of curriculum integration

After the STEM Academy two-day meeting in February, the team from Crowdon Primary School developed an Early Draft Plan for the first two terms of the school year (from February to June), which stated:

> By June we intend the grade 3 children to complete both design task 1 (car - forces) and 2 (vessel -properties of materials) with a specific focus on explicitly teaching the process. Considering the future we hope that both students and teachers can collaborate to develop inquiry STEM projects for our Term 3 and 4 units.

This suggests they were keen to begin with teacher directed integrated projects but to work towards a more student and teacher designed approach by the end of the year. However, challenges arose with perceived constraints from curriculum requirements and a school mandated scope and sequence of curriculum topics.

During the STEM Academy program, teachers were provided with the opportunity to act as students and to build a wind powered car using a small collection of consumable materials such as plastic straws, paper cups, A4 sized plastic sheets, sticky tape, pipe cleaners, stick skewers, and cardboard paper plates. Using this type of task as an example of an integrated STEM activity was modelled to the teachers by one of the Academy team members. Strategies to illicit student questions and to connect mathematics, science and design principles were discussed. This task became the first STEM learning experience implemented at Crowdon Primary School shortly after the first Academy session.

STEM Leader indicated it was easier to integrate the curriculum in grades 5 and 6 where the school's scope and sequence aligned more closely with the types of STEM projects they wanted to use with the students. She said, "it's most successful in upper primary" where we could "try to make them more project-based and try to cover across the subjects." Further, "I've had to develop a scope and sequence to align with our current science and HSIE units. People are seeing it's not just an add-on like an extra, it actually fits in the syllabus." It was evident the school had developed a scope and sequence for all subjects and that their STEM work needed to align with those plans. This led to constraints on what was possible and allowed little freedom for students' questions to be incorporated into the STEM projects, which appears to have been a missed opportunity as teachers were surprised by the engagement of students and their willingness to do more STEM work.

Inquiry-based learning designed and led by teachers

The STEM tasks and projects were designed and led by the teachers. Over time, they noted an increased interest and engagement of students, particularly those who were not typically interested in subject-based lessons. As the Librarian indicated, they "started small" with a teacher led approach but the tasks throughout the year continued to be smaller, teacher directed projects. The June School Report submitted to the STEM Academy indicated some of the earlier challenges when introducing the integrated STEM projects and supporting the students to work collaboratively.

> Initially we found that students had difficulties working together in groups and sharing ideas. After explicit teaching of both the design process and group work skills by the end of this unit we found we had increased engagement from students, and successful learning about the design process and students communicating ideas.

While teachers felt constrained by a scope and sequence of subject content and topics, when allowing students to investigate and explore new ideas, they were also surprised at students' awareness that they were using the STEM subjects to help them solve problems. Teachers shared examples of students describing what they were learning by naming the mathematics or science they were using. Librarian stated "… when we did the wind powered car, this one bright child said, 'okay, we're measuring the distance … it's a bit like a car, is that how you work out speed?'"

All expressed surprise when students who normally were less engaged began to enjoy making and creating practical solutions to problem situations. Chris commented "when we came back from the Academy, I thought let's just open this up and see what happens and let those kids go and I think the first time we did that, they were so excited." Further, "I had a couple of boys especially who were very mechanically minded, Lego and all that sort of stuff. They just thrived, they loved it … and they started to say 'are we doing STEM today?'" Similar views were expressed by Jazz whose students indicated they "wanted to do more of the making and designing." It appeared the students were associating STEM with hands-on tasks and suggests such practical work had not been a regular part of the school curriculum.

The four students who were interviewed (three girls and one boy) were unanimous in their desire to do more STEM project work. One of the girls indicated "doing STEM has helped me in maths and science. It helps me understand that a bit better" and another girl said, "my maths has improved … it's easier to remember things when you're actually doing hands on and not just reading from a sheet." When asked what projects they would like to be doing this year, the boy indicated he would like to "build the wind powered car again" so he could improve on his design ideas from last year. He had been making and designing things at home since his STEM work in 2017 and was disappointed that he had not done any STEM projects in grade 4.

The integrated approach to STEM and inquiry-based learning was not implemented in grade 4. All four of these students reported they had returned to ability groups for mathematics and completing worksheets focused on topics. When asked about this situation, Librarian indicated, "it is a challenge to get everyone on board." It seemed the two teachers responsible for grade 4 in 2018 had not been supported by the original STEM school team or by the school leadership to introduce integrated STEM curriculum and to do more project-based work with the classes who had been the trail blazers during 2017. While the original school plan embraced the approach of integrated STEM and inquiry-based learning across the school, changes in staffing and lack of building capacity for all staff in the school meant the changes were limited to a small number of teachers and their students.

Emerging knowledge of STEM by teachers

Librarian's role was to team teach with the grade 3 teachers during 2017 so that she could "lead them in the inquiry research model." She indicated that working with the grade 3 teachers "motivated them more to do more and to get them started to think outside the box of ways to do it." The grade 3 teachers also led a whole staff meeting to share what they were doing. Librarian indicated this recognised and encouraged Chris and Jazz's efforts. However, the desire to implement integrated STEM curriculum was not school wide when we visited in 2018, although both Chris and Jazz indicated they had used the same STEM tasks and projects with their new grade 3 classes.

The new school Principal was keen to see the integrated STEM program developed across the whole school. However, the STEM leader's efforts to support and further develop other teachers' capacity had been interrupted due to Librarian had to take personal leave during 2018. STEM Leader was passionate about continuing her efforts to develop integrated STEM across the school although she acknowledged that the school's initial Expression of Interest was probably too ambitious and that they should have started more cautiously to allow teachers time to trial ideas and to gain confidence. She indicated it can be very difficult to allow students flexibility in their projects and to not know how to answer some of their questions. She said, "kids will often figure it out for themselves … you don't have to have all the answers." She reiterated she needed to inform teachers it is not an "add-on" and that "it's actually covering the curriculum content."

Another area of teacher growth involved the use of technology in STEM projects. Both STEM Leader and Librarian were instrumental in assisting teachers with using a range of technologies, such as programmable devices, including Spheros^{TM} (https://www.sphero.com/education/) and Bee-Bots^{TM} (https://www.teaching.com.au/). Students learned how to code Spheros to follow a maze and power boats. One of the girls indicated she enjoyed these experiences and wanted to learn more about coding. In the student interview, the boy stated he enjoyed learning new technologies with the Librarian because "she really likes it and we like learning with her." While STEM Leader and Librarian were instrumental in driving the use of technologies, Jazz was still not entirely confident with their use even though the students' attitudes and aspirations in technology were impacted by the 2017 STEM program in the school.

Another way to build teacher capacity is to bring in experts from the community and to use their knowledge and interests to further engage students. Some attempt was made to do this in 2017 but Librarian commented they could have done more to access community experts who may have provided students with more information about STEM careers.

Developing support from school and community

The school used several strategies to engage the local community and other experts in their STEM program during 2017. One popular event involved inviting parents to the school to hear about the students' STEM work and engaging parents with designing and building the wind-powered cars. The students commented they enjoyed watching the parents' cars tip over when they were placed in front of the fans. Observing parents fail at what was perceived to be a simple task gave the students added confidence that they were learning important skills. The students were keen to help the parents redesign their cars based on knowledge of what would make the cars more stable and travel further.

When the students in grade 3 were tasked with designing moveable pop-up shops, a parent, who was a builder, talked to the students about materials and structures that might be suitable, answered their questions about building, and provided feedback on their ideas. One of the local hardware stores donated materials for the projects and representatives from the local SES (State Emergency Services – an organisation called upon to support residents in need of help when there are extreme weather events such as floods) talked to the students about safety in floods and strategies for rescuing people trapped by rising flood waters. Most of the community representatives who visited the school were male, which raises the question about whether this impacted the boys' attitudes more than the girls. Exploring this issue further is beyond the scope of this study.

Additional to these community connections, an organisation that visits schools to teach children about forensic science was invited to the school during 2017. Throughout the day, classes visited a display in the school hall with students participating in a range of activities such as finger printing and solving a murder mystery based on a set of clues. This event had quite an impact on the grade 3 students with one girl who was interviewed reporting she "really likes doing forensic science things" and would consider that as a possible career when she left school. Further, her sister was studying engineering at university and she was interested in that as well—of the group of four students interviewed for this study, she was the only one who expressed an interest in pursuing a STEM career when she left school. The remaining students expressed more interest in English and sport but voiced unanimously that they enjoyed the STEM project work and were keen to do more, particularly as it connected to their local community. Such responses suggest students were particularly engaged by the "hands on" approach adopted in the STEM projects and the opportunity to discuss local issues connected to their own experiences rather than the usual delivery of content and skills related to the STEM subjects. Perhaps the positive outcome for this school was the opportunity for teachers to witness the impact of inquiry-based learning and the use of local contexts to enrich students' school curriculum.

Conclusions and Recommendations

At Crowdon Primary School, after a year-long professional learning program for teachers and the implementation of several integrated STEM projects with grade 3 students, students were more positive about the STEM subjects and using STEM in future careers. Having implemented several teacher-designed and teacher-led projects, the students interviewed reported they preferred learning mathematics and science through projects and were keen to have more opportunities to do so. They liked learning about their local community and working with their peers to solve real-world local problems. One student suggested they could be doing "something around the community like planting more trees to make nature a bigger part of our community and just help everyone clean up." Adding to this idea, another girl said, "I'd like to get everyone involved because then it would change their attitude towards looking after the environment." Their comments indicate they were ready to pose their own questions and for the school to move to the next level of integrated STEM curriculum as advocated by Vasquez (2015) and Bybee (2013). This unfortunately has not eventuated.

As the grade 3 students moved into grade 4 with different teachers, they returned to a curriculum organised into siloes of disconnected subjects and being taught in more traditional ways with few opportunities for inquiry-based learning. For progress to be made, the school needs to develop a strategy to increase the capacity of all teachers to embrace the integrated STEM approach. Without a whole school plan to drive change across the grades, any potential gains or changes in students' attitudes and aspirations may be lost, as would any capacity building of teachers achieved during the project. The school leadership will also need to allow teachers the time and space to pursue more open-ended projects or to follow students' inquiry questions and then map learning outcomes back to the curriculum rather than teachers having to adhere to the school's mandated scope and sequence of content for each of the STEM subjects. This approach will require more leadership and further capacity building (Bolman & Deal, 2017), and the development of a school culture that celebrates such challenges and encourages teachers to explore these new possibilities.

These findings support other research identifying key components of successful STEM integrated models (Honey et al., 2014) but the study raises new questions about teacher professional learning into the design and delivery of integrated STEM programs. It also raises questions about sustainability and scalability in school systems where the demands on teachers' time appear to be ever increasing. In future, the larger data set gathered from all 13 schools in the Academy program, will allow exploration of more specific factors that influenced the shifts in student attitude and aspirations towards STEM choices. The more we understand the influential factors, the better we can design effective professional support for teachers in the development of integrated STEM education approaches. Armed with such evidence, the STEM Academy has the potential to support teachers in a range of contexts as they work in school teams to design programs that meet the needs of their students.

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RESEARCH REPORT

Responding to the Demands of the STEM Education Agenda: The Experiences of Primary and Secondary Teachers from Rural, Regional and Remote Australia

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Abstract: *In recent years STEM education has been the focus of Australian government funding initiatives, policy and curriculum development at the national and state levels and a key driver of school innovation. Principals, teachers and students have been called upon to develop their capability and interest in the individual STEM discipline subjects or to engage in interdisciplinary STEM activities. Much of the focus on STEM has been driven by a national agenda informed by the needs of industry, and research that indicates that the students graduating from schools and universities today with STEM qualifications will not be sufficient for society's needs. While the agenda encompasses more than individual teachers or schools, it is teachers who are at the forefront of its implementation in classrooms. In this paper we report on the perceptions of teachers about issues impacting on the effective teaching of STEM in rural, regional and remote Australia, and strategies they use to overcome issues/barriers and building the confidence and capacity of STEM teachers. Based on these, the paper reports some potential solutions to the issues faced by schools in rural, regional and remote Australia addressing the demands of the STEM Education focus.*

Keywords: STEM teaching; teacher capacity; STEMCrAfT; rural, regional and remote Australia; school leadership.

Introduction

Developing an innovative and dynamic knowledge-based economy is recognised as a global pursuit (Kearney, 2011). The Australian Chief Scientist stated that a "workforce with a substantial proportion educated in Mathematics, Engineering and Science (MES) is essential to future prosperity" and a "critical underpinning for the future of innovative economies" (Office of the Chief Scientist [OCS], 2012, p. 6). In both reports by Kearney and the Chief Scientist, teaching was identified as a fundamental priority for achieving such a workforce, with the latter highlighting "inspirational teaching" as a key recommendation.

The term STEM is now ubiquitous (Fraser, Earle, & Fitzallen, 2019) and used in the literature and government reports to encompass both the teaching of the individual curriculum areas (science, digital and design technologies [encompassing engineering principles], mathematics) and the teaching of these subjects in an integrated manner through student engagement with real world and authentic problems (Honey, Pearson, & Schweingruber, 2014). STEM teachers include teachers who teach science, digital and design technologies and mathematics and/or integrated STEM through inquiry and problem-based learning, in either primary or secondary school settings. A significant difficulty facing

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the implementation of STEM education in schools is the chronic shortage of teachers appropriately qualified, with adequate content knowledge and pedagogical content knowledge or expertise to teach science and mathematics throughout Australia (Hobbs, 2013). More than a third of Australian secondary mathematics teachers and a quarter of science teachers are not adequately qualified to teach in those fields (Productivity Commission, 2012). It follows that being taught by teachers without expertise in a teaching area negatively affects student achievement (Whitehurst, 2002). Teachers who are teaching out-of-field, that is, teaching a subject for which they are not qualified (Education and Training Committee, 2006), often have little confidence or self-efficacy to teach science and/or mathematics individually. It would be even more unlikely that such teachers would have the capacity to reframe their teaching and their students' learning or adopt new pedagogies for integrated STEM argued by Hobbs, Cripps Clark and Plant (2018). Importantly, in relation to the arguments we pose in this paper, rural, regional and remote (RRR) schools experience these issues to a greater extent than schools in urban areas.

Teaching in rural, regional and remote schools

The term "regional and remote" is used to encompass all areas in Australia outside its major cities. In relation to the research reported here, undertaken with participants from Tasmania and Western Australia, the Australian Standard Classification System (Australian Bureau of Statistics [ABS], 2016) classifies the majority of Tasmania as regional and its west coast and some areas of the east coast deemed remote, while the majority of Western Australia is categorised as very remote.

The keys issues cited in the literature concerning teaching and learning in RRR areas of Australia are: the difficulty in recruiting, retaining and supporting teachers (Halsey, 2018) and potential impact of out-of-field and inexperienced teachers on the quality of teaching and student learning (Ingvarson et al., 2014; McConney & Price, 2009) and teachers' beliefs about RRR Australia (Kelly & Fogarty; 2015). The need for STEM-literate parents (Timms, Moyle, Weldon, & Mitchell, 2018) as well as community understanding of and engagement with education and STEM (Council of Australian Governments, 2015) have also emerged as key to strong STEM learning environments.

There is much research documenting the issues faced by teachers in RRR schools and the challenges for recruiting teachers to teach in these locations (e.g., Cuervo & Acquaro, 2018; Lamb, Glover, & Walstab, 2014). In recent years the focus of policies has been on providing incentives to teachers to take on rural placements, including financial gain and/or cancellation of debt, and rewards through subsequent desirable placements (Reid et al., 2010). Once teachers take up a position in RRR schools, they may experience issues that undermine their decision to stay (Rural and Regional Affairs and Transport References Committee, 2009). These include professional isolation and the inability to build advice networks naturally (Baker-Doyle & Yoon, 2011), as well as the lack of access to mentoring expertise, release time and collaboration, and poor access to technical and support services (Sullivan, Perry, & McConney, 2013). Furthermore, principals in these schools may be inexperienced but are required to manage a large proportion of beginning teachers and a transient teacher workforce with high rates of teacher turn-over (Handal, Watson, Petocz, & Maher, 2013).

First year out and out-of-field teachers are common in schools in RRR Australia (Hobbs, 2013; Lyons, Cooksey, Panizzon, Parnell, & Pegg, 2006). Such teachers are known to struggle initially to teach effectively, which may result in them feeling inadequate and stressed, influencing "the extent of the success of their development in teaching as a profession" (Steyn & du Plessis, 2007, p. 149). In some states in Australia, mentoring of first year teachers is mandatory (Department of Education and Early Childhood Development, 2012), based on the premise that the exchange of ideas, knowledge and experience between colleagues can contribute positively to teacher professional development, and reduce teacher attrition (Ingersoll & Kralik, 2004; Smith & Ingersoll, 2004).

Kelly and Fogarty (2015) have argued that the barriers to attracting and retaining teachers in schools in RRR Australia are many and complex. They and other researchers highlighted the impact of internal representations of rural life that underpin teachers' consciousness about rural teaching (Reid et al., 2010), the psychology of teachers, their sociological context and their behavioural intentions (Kollmuss & Agyeman, 2002), as key factors contributing to barriers to teachers electing to teach in rural schools. Handal et al. (2013) speak to the internal factors outlined by Kelly and Fogarty (2015), indicating that teachers who take up positions in RRR schools do so due to "a perceived sense of a stronger staff collegiality; because of the attraction of a rural ambiance and the desire to gain exposure/experience in rural education, and to help rural and remote communities" (p. 13). Nevertheless, a recent longitudinal study of pre-service teachers conducted by Cuervo and Acquaro (2018) found that despite having a positive outlook toward teaching in an RRR context, all their participants (n=8) held deficit views about rural schooling. Such views included that schools are poorly resourced and staffed and that they make do with teachers teaching out-of-field. While some caution is needed in making generalisations from such a small study, this research does signify the need for further exploration of the views held by teachers in RRR contexts.

Teachers are an important part of the community and according to Halsey (2018) "have the most direct impact on children's learning in schools" (p. 38). While attracting and retaining teachers remains an issue as discussed, of equal importance is the RRR teachers' academic capabilities and the personal attributes needed for teaching (Teacher Education Ministerial Advisory Group [TEMAG], 2014). TEMAG highlighted the importance of the teachers' commitment to place and people and, as Halsey summarized, their role in "building student achievements and successful post school pathways" (p. 39). The consciousness that teachers bring to their teaching context influences both their approach to teaching and the expectations they have of their students. McCarthy, McCourt, Ikutegbe and Zhou (2018) found that student outcomes and their intrinsic motivation for studying improved when their teachers had high academic expectations of them and presented them with challenging work. Teachers may also hold unconscious biases (Lavy & Sand, 2015) and communicate their expectations to students. This conclusion has been supported by others (e.g., Beyerbach et al., 2009) who found a correlation between student achievement and teacher expectations or beliefs (e.g., girls do not do mathematics [e.g., Agbley, 2015] or physics [e.g., Zohar & Bronshtein, 2005]).

Communities are key to educational attainment in RRR Australia. In describing the importance of community and family, James et al. (1999) summarized the outcomes of earlier work of Williams, Long, Carpenter and Hayden (1993) who argued that "…rural disadvantage is in the main part related to family and community attributes, contending that the principle determining factor is the extent to which education is valued and promoted in the family and local community" (James et al., p. 10). More recently, Watson et al. (2017) reported that members of the RRR communities they surveyed believed that students are either academic or not (p. 65). This supposition, Watson et al. argued, would mediate student aspirations for further study. In their study participants made specific reference to the values held by the parents regarding education and their lack of understanding of the value of education (p. 66). As students are perceived to assimilate the attitudes held by their parents towards education, such a limited understanding of education could influence students' responses to the pathways to further education that are offered to them.

Challenges for teaching STEM and S.T.E.M subjects in RRR

Research has identified that students in schools in rural Australia are less-advantaged than their urban counterparts (Human Rights and Equal Opportunity Commission, 2000); they are less likely to finish secondary school (Lamb et al., 2004) or attend university (ABS, 2013). Such disadvantage has also been identified in the data gathered in relation to science and mathematics education (Sullivan et al., 2013). Data collected in two major international studies (Program for International

Student Assessment [PISA]; Trends in International Mathematics and Science Study [TIMSS], have consistently shown that students in rural and remote schools perform at a lower level in both mathematics and science than their metropolitan counterparts (Aldous, 2008). Sullivan, McConney, & Perry (2018) noted that Australia has one of the largest gaps in urban-rural achievement in PISA.

An analysis of the international data collected through PISA indicated that urban schools are:

> usually larger, have a more socio-economically advantaged student body, enjoy greater responsibility for resource allocation, are less likely to experience staff shortages, are more likely to have a higher proportion of qualified teachers, and have higher student-teacher ratios than schools in rural areas and towns (Organisation for Economic Cooperation and Development [OECD], 2013, p. 2).

These findings align with the factors identified in Australian research as contributing to lower student performance in science and mathematics in RRR schools (Sullivan et al., 2018). In particular, the difficulty of recruiting and retaining teachers (Goodpaster, Adedokun, & Weaver, 2012; Handal et al., 2013; Sullivan et al., 2013) and the consequent relative inexperience of rural teachers (Aldous, 2008; Handal et al., 2013; Hobbs, 2013; Lyons et al., 2006) as discussed previously. Schools located in the smallest rural communities have the lowest socioeconomic profiles and "the lowest academic performance and the largest shortages of teaching staff and instructional materials" (Sullivan et al., 2013, p. 354). Such inequitable distribution of resources (including educational resources, instructional materials, qualified and experienced teachers) has been found to be associated with students' learning and educational outcomes (Chiu & Koo, 2005). While the context of the school may be a source of constraints to student learning outcomes, school leadership and strategic resourcing have been identified as key to overcoming them (Robinson, Hohepa & Lloyd, 2009).

Du Plessis, Carroll and Gillies (2014) stressed the importance of school leadership in embedding support for STEM in their schools; leaders who understand the issues and who are connected with teachers' experiences in classrooms and can engage in "inside-out" (Darling-Hammond, 2010) school improvement. Berlin and White (2012) recommended that those new to teaching STEM disciplines work collaboratively (inclusive of team-work, team teaching, mentoring and collective engagement in professional learning) to design and implement STEM teaching and learning. Steyn and du Plessis (2007) argued that an important aspect of supporting teachers teaching out-of-field is the involvement of the school community in recognising the impact that this phenomenon has on the learning environment. They recommended that school leaders develop a shared sense of purpose among parents, teachers and learners and the broader community resulting in "cooperation between the home and the school [which] creates a secure environment in which effective learning can occur" (p. 155). Such reciprocal engagement and shared understandings of the importance of STEM education, may go some way to influencing students' interest and engagement in STEM subjects.

Not only can community engagement support teachers teaching out-of-field in RRR contexts, such engagement may also influence and be influenced by the espoused purpose and goals of the school. In the report, *Inspiring Australia: A National Strategy for Engagement with the Sciences* (2010), the Steering Committee for a National Science Communications Strategy argued that Australia "must engage the wider community in science" (p. xiii). The Chief Scientist later reasoned that at the heart of such community engagement is scientific literacy, for which a higher level "…within the broader community is essential for a modern, well-informed society" (OCS, 2012, p. 10). Scientific literacy will be influenced by the extent to which schools sustain focussed initiatives aligned with purposeful STEM goals, and both communicate with and co-opt their school and local community into achieving them.

According to Roberts (2018), a key issue for STEM education in RRR contexts is lack of understanding on the part of students and teachers as well as parents, of the ways rural industries operate and the capabilities they need in their workforce. He found that the link between school subjects and present and future careers in rural industries was missing (Roberts, 2014). As those working in and leading rural industries were also disconnected from the language of schooling and curriculum, they were not necessarily able to communicate their needs and relate them to subjects that students would benefit from studying in order to enter their industry. Roberts (2014) summarized this as being a significant language (and hence understanding) gap between students, teachers and rural industry and communities.

The issues related to school leadership and resourcing, educational outcomes and community understanding of and engagement in STEM education, indicate that a more systematic approach to solving the problems faced by teachers and more specifically STEM teachers in RRR contexts is required in order to both attract and retain quality teachers of STEM. Australia has the *National STEM School Education Strategy* (Education Council, 2015) for improving STEM teaching and learning, as well as dedicated national, regional and/or local centres to address this purpose. Other countries have implemented similar strategies (e.g., the Netherlands, Belgium, Norway, Ireland, France, Israel, Switzerland, Italy) with centres that aim to improve the quality of STEM teaching and sometimes to increase the popularity of science and technology (Kearney, 2011). A common approach in Australia described by Murphy, MacDonald, Danaia, and Wang (2018) is to establish networks of teachers, teacher trainers and other relevant stakeholders, often at the regional level, with the aim of implementing curricular reform and supporting initiatives favouring inquiry-based learning (e.g., cross-disciplinary, thematic or project work).

The extent to which these national, regional and/or local initiatives have begun to address the issues known to impact upon teacher quality, particularly in relation to teachers of STEM in RRR, is as yet unknown. The purpose of the research reported here was to investigate the following research question: *How do teachers address issues that they believe impact upon their ability to teach STEM (subjects) effectively?* In this paper, we both explore these issues with RRR STEM teachers, and examine how they cope with them by explicating the strategies they have either used or that they believed might help. We also explore the extent to which their proposed strategies align with school, state and national initiatives.

The project

In this paper we report on some outcomes of a project undertaken by the School of Education and the Centre for University Pathways and Programs (CUPP) at the University of Tasmania funded by the Australian Department of Education, through the Australian Maths and Science Partnerships Program initiative. The project was titled *Evaluating and selecting STEM resources: Capacity building for teachers in rural and regional schools* (STEMCrAfT). The aim of STEMCrAfT was to build capacity for RRR STEM teachers using a peer support model. The project arose out of the recognition that staffing challenges in RRR schools can mean that teachers with limited expertise in mathematics, science and technology, teach in these subject areas and this impacts on student achievement and subsequent student ability to engage in STEM pathways to tertiary learning.

STEMCrAfT brought university teacher educators with expertise in mathematics and science teaching and relevant discipline representatives from science and engineering together with rural and regional teachers of science, technology and mathematics – both experienced (> 5 years teaching in the STEM discipline) and novice teachers (< 2 years teaching in the STEM discipline). It aimed to identify the tacit knowledge of experienced science and mathematics teachers through them reflecting critically (Schön, 1983) on their practice and to provide novice and out-of-field teachers access to their expert ways of selecting teaching resources. As a result. a framework for selecting resources was developed, and field tested iteratively by both experienced and novice teachers. Details about the framework, the process by which it was developed, and its perceived usefulness are presented elsewhere (Beswick, Fraser & Crowley, 2016; Kilpatrick & Fraser, 2018).

In this paper, we report the outcomes of a reflexive thematic analysis (Braun & Clarke, 2006) of responses to questions asked of participant teachers, prior to them engaging in the collaborative development of the framework. This approach was deemed the most appropriate to unearthing participants' perceptions of the issues that they believed impacted upon their ability to effectively teach STEM (in either an integrated manner or as individual disciplines) in their schools. It also unearthed their suggestions for possible strategies that would enable these issues to be addressed.

Method

Participants comprised of 26 experienced and 11 novice or out-of-field teachers of science and mathematics from early primary to senior secondary. Two workshops were held, one in each of two Australian states, Tasmania (18 experienced, two novice) and Western Australia (eight experienced, nine novice). All participants were nominated by senior education systems leaders to attend the workshop, either due to them being recognised as experienced science, mathematics and/or technology teachers or as novice teachers who had expressed interest in these discipline areas. Of the 37 participants, 21 were female and 23 taught in secondary schools. The initial workshop spanned three days and was held in Tasmania. It resulted in the development of a draft framework for selecting resources by the project team, which was field tested and enhanced by the novice teacher participants. The draft framework was taken to the second day-long workshop in Western Australia where participants contributed to further refinements of the framework, after which it was deemed to be at a stage where it could be disseminated and trialled.

Prior to participating in this collaborative exercise in both of the workshops, participants were asked to respond to the following set of four survey questions:

1. What do you perceive as the main issues affecting the effective teaching of STEM in your own context?
2. What strategies have you implemented that serve to overcome these issues/barriers?
3. What do you perceive as the main issues affecting the effective teaching of STEM for teachers teaching out of field and/or teaching in rural, regional and remote contexts?
4. What do you identify as particular strategies that would build the confidence and capacity of STEM teachers teaching out of field and/or teaching in rural, regional and remote contexts?

The aim of getting participants to consider such questions was three-fold. Firstly, the project team was generally interested in unearthing the issues that teachers felt were being experienced in schools interested in teaching STEM (as well as the individual discipline subjects) and the solutions that they felt might mitigate against them. Secondly, the project team wanted to ensure that as much as possible any framework developed contributed to solutions to the issues identified. Finally, the team wanted participants to be able to articulate any negative sentiments they might have held about STEM teaching and set them to one side, prior to engaging positively in the collaborative professional learning the project presented through explicating their practice. Participants' responses to the four questions provided through a hard copy survey were transcribed into qualitative data analysis software, NVivo, and analysed thematically. After an initial reading of participants' responses to the survey, preliminary themes or codes were identified and subsequently grouped together. They were then checked for emerging patterns, variation and consistency through iterative reading and re-reading by the authors and reference to the literature.

Participant responses are reported below using unique alpha-numeric codes (T: Tasmanian participant; W: Western Australian participant; P: Primary; S: Secondary), and any emphasis incorporated by the participant (e.g., use of capital letters) is retained in the quotations.

Results

A reflexive thematic analysis of participant responses within and across all four questions revealed five aspects of the education system that both impacted on STEM teaching and underpinned the strategies identified to mitigate them.

1. The students
2. Teacher capacity
3. The system within which they operate
4. Availability of quality resources and resourcing, and
5. STEM and the wider community

Each of these five themes are discussed in relation to the four questions. Due to the related focus of questions and responses, Questions 1 and 3 are reported together, as are Questions 2 and 4.

All participants in the project had either taught in rural, regional or remote (WA in particular) regions previously or were currently doing so, and could, therefore, speak from experience about the issues particular to STEM teaching (experienced either as STEM subjects taught separately or in an integrated manner without explication) in these contexts. While the issues and strategies identified for teaching STEM in their own contexts (Questions 1 and 3) were evident in their answers to Questions 2 and 4, others that were particular to RRR contexts were added or discussed in more detail.

Questions 1 and 3: What do you perceive as the main issues affecting the effective teaching of STEM in your own context (Q1)…for teachers teaching out of field and/or teaching in rural, regional and remote contexts (Q3)?

The Students: Participants indicated that teachers' ability to teach STEM effectively was affected by their students' attitudes to, and capacity to learn and/or engage in integrated STEM or individual STEM subjects.

The impact of students' low literacy and numeracy levels on their ability to learn in STEM subjects was highlighted. Both students' lack of a deep understanding of mathematics and their limited exposure to science concepts in earlier stages of their education were noted as influencing their learning in later years. This lack of basic knowledge was believed to impact on their ability and/or interest in further study, for example, *Students have limited exposure and understanding of the science concepts. They struggle to do well in pre-tertiary biology and chemistry* (TS1).

Participants referred to students' lack of motivation to study these subjects, citing their perceived lack of relevance: *Student motivation is secondary. Motivation is falling away earlier, even in late primary. High school students don't see the need for future jobs. Don't see the people who are using the math/science* (TS11). Low aspirations and an unwillingness on the students' part to put in the effort to develop their subject understandings, as well as teachers' aspirations for their students, were cited as reasons for students' lack of engagement in STEM subjects: *Because of the low aspirations of students/teachers in relation to maths/science, students do not engage. They get a negative attitude towards the subjects* (TS5). One participant linked the low STEM proficiency and student motivation with it having a low priority in schools: *Student motivation: STEM area often a 3rd or 4th priority area* (TS15).

Student numbers in RRR schools can be small, with one participant highlighting that this results in the need to address *challenges of special needs students in a mixed ability composite class* (TS11). Participants highlighted a feature of RRR contexts in Western Australia – inconsistent student numbers. They noted that numbers were inconsistent due to either the irregular attendance of particular students or the transient nature of the population. Together, this resulted in the high turnover of students—especially, in mining areas in Western Australia. While details of the impact of this phenomenon were not provided, it could be presumed that teachers who must accommodate the needs of itinerant students in an ongoing way, may perceive that this impacts upon their ability to teach a unit of work effectively.

Teacher capacity: Participants recognised the pivotal role of the teacher in the learning environment and determined that both teacher capacity (personal attributes and/or capabilities) to teach STEM and the limitations imposed upon them due to external factors impacted on their teaching effectiveness.

Participants highlighted a lack of science and/or mathematics content and pedagogical knowledge in STEM teachers, as a result of inexperienced and/or out-of-field teachers teaching STEM subjects. These deficits were perceived to impact on the quality of teaching and learning; for example:

> *Misunderstandings of effective teaching and learning approaches that build and develop students' understandings. Serious ignorance of what pedagogy actually means, let alone pedagogical content knowledge – don't even go there lately with the blank looks I get.* (TS4)

The development of teacher capacity for teaching STEM was perceived to be limited by a lack of time for expert STEM teachers to effectively share their expertise or to mentor less experienced staff. This lack of time in conjunction with the limited number of science and mathematics teachers in schools, also impacted upon their ability to plan, collaborate and to identify relevant resources. As one less experienced teacher commented: *At our school I am the only Maths/Science teacher. There is no-one with whom I can discuss and plan my lessons* (TS6).

When considering issues specific to RRR contexts, participants noted that it is more likely that RRR schools are staffed with inexperienced teachers: *Rural teachers are of the least/less experienced (new) teachers* (TS13) and/or out-of-field teachers. Consequently, RRR teachers often lacked sufficient content knowledge and/or the confidence to teach in STEM subject areas. In particular they have *low confidence to perform experiments (safety issues)* (TS5). Both inexperience and lack of expertise were identified as being linked with a teacher's reluctance *to try new things* (WP13) and/or teachers not being *confident to ask for help* (TS5).

The isolation of teachers in RRR schools was believed to limit professional conversations and make building professional relationships or collaborations more difficult. Participants indicated that they lacked support and did not have access to good role models or mentors, often *working on own so need to prepare every unit topic, assessment task etc. which takes time* (TS8) with little time to organise and plan. Again, a lack of time was identified as having pivotal impact teaching in STEM in RRR contexts, for example:

> *The students prefer hands on activities and get motivated through these activities, but we teachers lack time to organise these things at our Schools where only one person is responsible for teaching and preparing resources for STEM.* (TS6)

Participants mentioned a *lack of time to build resources* (TS13) and not enough time for *building the relevance* [of activities/curriculum] (TS7).

The system within which they operate: The importance school leaders give to STEM staffing was highlighted as key to effective teaching and learning practice.

In particular, the impact of principals' disinterest in STEM was identified: *Management (school principals) not perceiving STEM (especially Science) as important so resourced last, get 'any old teachers'* (TS2). Overall, staffing was perceived as problematic, for example:

> *The lack of forward planning by schools. Often maths/science teachers are the last to be sourced. The school picks up whoever is 'left over'. [These teachers then] get the "worst" loads as the "top" classes need to be covered by trained/experienced teachers. Those teachers then need to spend more time supporting the less experienced COPE. But we all know that.* (TS4)

As one participant noted, the high level of teacher turnover affects the quality of teaching STEM subjects:

> *Some teachers (non-expert) that end up teaching these subjects are on short-term contracts and pretend to be doing a good job because they are afraid of not having their contracts renewed so they do not seek expert help.* (TS2)

This participant went on to explain that in his or her view such practices influence students' interest in STEM subjects: *Because of the above, students do not engage, they get a negative attitude towards the subjects.* (TS2)

Reflecting on RRR contexts, participants noted that staff turnover in schools is high and staff numbers are generally low in the smaller schools. Participants identified that not having teachers capable of teaching STEM subjects in these RRR schools makes staffing the required number of teaching areas/levels difficult, and/or if a STEM teacher is available, it creates an overwhelming workload for them. This means that there are few staff to 'cover their teaching' and it is *harder to get release time for PD (need longer)* (TS11).

The ways in which schools structure classes was also perceived as limiting teacher effectiveness: *Ability levels of children. I have a year 2/3 class - 7+8 year olds that range* [in ability] *from Foundation level to Year 10 level* (WP3). It was also recognised that gifted students and students with special needs must also be catered for. Several participants from Western Australia identified school and system requirements for documentation to cover risk as limiting engaging learning activities and opportunities: *'Red tape' that prevents 'fun' + engagement (excursions/ethics policy)* (WP5).

The impact of the Australian Curriculum was also identified as negative, with one participant citing its crowded nature: *Time in a crowded curriculum as I teach all subjects trying to cover all science concepts in a year* (WP7). Another referred to its *huge range of content* (WP5) and several others perceived it as constantly changing thereby impacting upon teachers' ability to plan and prepare appropriately. At least one participant recognised the impact of other educational goals and/or demands on teacher practice and student learning in STEM: *The demands of many other things put on by DoE* [Department of Education] *and society. Sometimes teaching knowledge and skills come second or third* (T8).

In relation to RRR schools, it was noted that with few staff and little access to professional learning or expertise, the Australian Curriculum was implemented without support or guidance about what aspects on which to focus. One participant suggested that *support for PL from their admin* was lacking, highlighting that *admin have to believe it is worthwhile* (TS3). As a result of this lack of support, professional learning and isolation, participants felt that RRR teachers lacked confidence in the quality and/or appropriateness of their teaching and student learning outcomes: *moderation of work?? How is this done??* (TS8) as *moderation* [is] *harder in small isolated schools* (TS11).

Availability of quality resources and resourcing: Participants differed in their experience of

STEM teaching resources, discriminating between teaching resources including kits, equipment and support, information technology (IT) infrastructure and access, and available funding.

Tasmanian teachers tended to recognise that while there are a *great MANY OUT THERE* [emphasis provided in participant response] (TS3) and they are *easy and available* (TS7), there is a lack of *funding for resources and equipment* (TS11), which themselves, can be insufficient for purpose. As noted earlier, time was highlighted by participants as a limiting factor, in particular: A *lack of time to organise resources* (TS6); and to identify suitable resources: *What are the best resources for teaching the AC* [Australian Curriculum] *outcomes? Not time to find out* (TS15). This participant went on to explain that this situation leads to a *reliance on textbooks which generally provide poor explanations of concepts and not used by students (despite paying for them).*

IT infrastructure was identified as an issue for some participants, particularly those from RRR in Western Australia: *Internet access: We are a satellite school very poor coverage* (WP7). Participants also identified a lack of support staff: *There is no lab assistant, so I have to look after the Science lab. I find it difficult because of limitations of time* (TS6).

In the RRR context in particular, funding was perceived to be inadequate, with their isolation impacting upon *travel costs for excursions* (TS5) and resulting in a *lack of well-equipped science labs, lack of science lab assistants make it more difficult* (TS6). One participant felt that there was a *lack of resources for gifted* [students] *especially in these* [RRR] *schools* (TS11). The lack of access to resources and expertise makes it difficult to keep up to date adding to their planning requirements as the *liberty of buying ad hoc* [resources] *not there, have to plan way ahead, can make it difficult to do things as the students come up with ideas* (WP15).

STEM and the wider community: Participants referred to the potential negative impact that a community (parents, the local community, industry) that lacks understanding of STEM and STEM education can have on the effectiveness of STEM learning.

It was noted by one participant that families are influential in guiding student participation in STEM, while another noted the persistence of a *"girls don't do science"* (TS13) mindset. Yet another suggested that subject choice is influenced by community perceptions in regards career options: *Any good students are encouraged to go to Health Sciences rather than exposed to 'pure' sciences such as chemistry/physics* (TS5).

Participants believed the importance of STEM subjects was not necessarily recognised in the community: *Parents/students don't see the importance of STEM subjects (exception maths – but only because the grade is 'counted' by employers* (TS5). This participant also observed that there are *no/minimal links to Science/Maths to rural/regional setting (e.g., industry)*. In relation to RRR context, it was noted that *community perception of STEM as a united/integrated & important discipline* (WP15) is limited, with another participant identifying that there was *not much enthusiasm for STEM related subjects in the community* (TS1). Finally, the way STEM subjects are taught was noted as having a *lack of interest/relevance of local community/culture* (TS8) and the content and/or the way students engage with it, resulting in a lack of *relevance to students (when will I use this?)* (TP9).

Questions 2 and 4: What strategies have you implemented that serve to overcome these issues/barriers (Q2). What do you identify as particular strategies that would build the confidence and capacity of STEM teachers teaching out of field and/or teaching in rural, regional and remote contexts (Q4)?

Participant responses to Questions 2 and 4 aligned well with their identification of the issues relating to STEM teaching, with responses to these two questions including both personal strategies for teaching and learning in STEM and strategies that they think would "fix" the issues.

The Students: Responsibility for increasing interest, engagement and student outcomes in STEM was perceived to rest firmly with the teachers and school system.

While participants identified a lack of student motivation and aspirations for STEM as issues, the strategies they nominated for ameliorating them focussed upon teacher practice and the provision of learning support (foundation courses, literacy support and targeted tutorials). Participants highlighted the need to provide engaging lessons with content that is relevant to individual interests and their lives outside/future after school to improve student engagement in STEM subjects. Such learning experiences should be both appropriate to ability (high and low achievers) and challenging for students: *Teach more challenging science/maths rather than accept minimal mediocrity* (TS5).

Teacher capacity: The teacher, the teaching team, the school and the broader education system have responsibility for improving teacher skills, expertise and experience.

At the individual level, suggested strategies included: the teacher being strategic and targeting deep learning: *emphasis on one learning concept per semester* (WP1) in *order to cover concepts properly* (WP7)*,* while continuing to innovate: *Increase excursions to local industries, e.g., Savage River Mines* (TS5). One participant suggested it would be useful for teachers to *redesign the way in which maths is taught. Use a problem-solving approach to identify skills needed* (TS15), while another encouraged teachers to be adaptable: *trying to match interest of each student with ability and look for the appropriate individual ways of delivering the topic* (TS7) in order to both improve the learning environment and enhance student learning.

Having an adaptable teaching approach, being able to cater for a diversity of abilities in the one class, using content selectively, contextualising curriculum and making STEM learning "hands-on", were highlighted as important for teacher practice. Exposing students to the teacher's *passion and interest is the key* (TS3) as well as his or her *life experience – bring it into the classroom* (TS13) were noted as important for engaging students in and inspiring them about STEM. Curriculum integration and *cross-curricula approach across learning areas and ages* (WS14) was also identified as important for achieving curriculum relevance and effective STEM teaching and learning.

Support for less experienced teachers was viewed as an important responsibility of more experienced teachers and the school (system) with individual teachers *mentoring and "piggy back" teaching to assist teacher confidence and teacher skilling; peer buddy - side kick training - learning another person's skills, everyone has an understudy* (WS16).

The System within which they operate: Overall the school principal [and discipline leaders] was identified as being responsible for, contributing to and enabling quality STEM teaching and learning.

Principals provide approval and support for teachers implementing the strategies articulated earlier, and they or their delegates are responsible for timetabling teaching sessions and ensuring that *learning area meeting times given priority* (TS8) to enable collaboration. Principals approve and support *school-based PL whereby we go through practicals to give them confidence to teach* (TS2) and the establishment of teaching teams: *new teacher mentoring and sharing of workload – share preparation, assessment, common resources, collaborative planning and timetabling* (TS8) as well as in-class observation and *swapping classes* (TS4) for *expertise in topics* (TS11). They approve class structuring, for example, *streaming for maths for some year levels* (WS3) and authorise the structuring of the timetable to facilitate the achievement of educational goals, and to *build meetings of teams into the school timetable* (TS11

School leaders are responsible for *developing a whole school business plan outlining targets up to "year xx" in all learning areas* (WS14) and advancing *a whole school program for science in line with the Australian Curriculum, which offers specific resources* (TP14). Principals can also lead the development of a whole of school *communication strategy* [for STEM] – *public relations –*

schools – media, to raise its profile and stimulate interest. They contribute to lifting the bar for STEM interest and engagement through supporting *annual science expos for feeder primary school students to motivate the students from an early age* (TS2) or establishing a *primary school extension program* (WP5).

System leaders can empower *local schools – using school data to identify needs* (TS15) for STEM enhancement, and through their structures: *Teacher development schools* (WP5). Participants felt that school systems can build capacity systematically through establishing *support networks, cluster models* (T3) and *network meetings amongst other primary schools and high school* (W3) to enable inter-school support and the development of professional learning communities. One participant highlighted that some STEM areas are more in need of strategic and targeted support than others: *Physics workshop for high school teachers in Australian curriculum topics* (TS8) and principals can build capacity by instigating *workshops for high school curriculum leaders, e.g., new Australian curriculum areas, after school, free* (TS11). Participants recognised the usefulness of *school and system content experts working with beginner teachers* (TS11), with the former receiving *recognition of* [their] *skills – fast track reward those that can* (TS3). It was also suggested that students would benefit from having *good teachers teaching lower down the school* (TS11).

Availability of quality resources and resourcing: Quality resources (including IT infrastructure and access) and appropriate resourcing of and support for teachers (including professional learning and mentoring) were highlighted as essential for quality STEM teaching and learning.

Throughout their practice, teachers are *continuously looking for engaging resources* (TS7), an *effective, easy and cheap resource to engage students, e.g., physics* (TS7) and *use interesting/attention grabbing resources* (TS10) to interest students in STEM learning. One participant indicated that s/he often uses *resources that I borrow from STEM department at "university"* (TS6) and *include(s) as many hands-on activities as I can*. Whichever resources they choose, participants emphasised the importance of catering for student diversity and sharing good quality resources.

Participants commented that the problem with lack of time and sufficiently qualified STEM teachers in RRR schools could be ameliorated through the provision of suitable *resource packages supported by demos and regular PL* (TS2). The increased *availability of resources especially the kits and lesson plans to go along with them*…with *workshops on how to run lesson using those kits and plans* (TS6) was perceived to free up RRR teacher time and enhance the quality of their teaching. The usefulness of such *units of work already prepared that just pick up and go with at various levels* (TS8) was reiterated by another participant, while a third saw the availability of a *reliable and successful resource…as a beginning point for teachers to build their own knowledge and practice on* (TP14).

Participants felt that both isolation and teacher capacity could be addressed through the building of *networks that ACTUALLY* [emphasis in participant response] *work – someone paid to do the coordinating (we see this as a great idea, but no-one has the time)* (WS2); creating supportive network clusters between local primary and high schools and *linking less experienced teachers with more experienced/confident teachers* (WP5). Technology (if available and reliable) was perceived as assisting in the creation and maintenance of these networks. It could provide teachers with access to regular webinars to discuss issues and to provide assistance and support, and online forums linking RRR teachers with experts and city schools. Teachers could also access online mentors, view videoed lessons of good practice, and be participants in "beam in a class". Technology is also essential to facilitating the participation of dispersed teachers in meetings via Skype (or similar) and providing access to library resources. The new technologies available in some RRR schools were considered key to the development of students' technological skills as they are tools for *integrating* [technology] *into all areas of the curriculum* (WS14).

Information communication technology (ICT) resources were noted by some participants as being key to their practice, and to developing students' subject-specific skills: *used IT resources such as Mangahigh and Khan Academy to give students time to work at their level in maths* (TP14). ICT resources can be expensive, and participants recognised that to build up a sufficiently effective resources requires targeted funding: *gaining funding for more technology* (WP4) to ensure *ICT support, building ICT resources (iPad, computers, apple tv)* (WS14). The importance of applying for targeted *grants/funding* (WP5) *from community grants* (WP13) as well, was raised by several participants from Western Australia. Another participant described a strategic approach to building ICT capacity, interest and resourcing: *very persistent in trying to get other staff on-board, formed ICT committee to assist in making those decisions; reviving computer lab to increase engagement* (WP15).

While technology was perceived as being useful in reducing isolation and building capacity, one participant suggested that face-to-face contact is also important, and that the system should *have experts go out to them* (TS13). Mentoring was a commonly expressed strategy: *across schools for small schools* (TS11) and/or *whether school or area based or online/distance* (TS10). Again, funding and leadership in support of professional learning was seen as key: *principals should ensure that their teachers are appropriately mentored, with teachers from other schools if necessary. Build in visits to other schools, see sessions being modelled* (TS11). For less experienced STEM teachers, *give these people changes to shadow…see the good operators* (TS3), and bring the professional learning to them, for example, *further training made available in the Pilbara region* (WS14). While moderation was identified as being difficult in RRR areas, one participant suggested that a good use of funding would be to *bring rural teachers to the moderation session to meet with the city teachers* (TS13).

School relationship with the wider community: To increase student interest in STEM, participants highlighted the importance of parental, community and industry engagement and the teacher/school role in enabling this engagement as well as enhanced understanding of the relevance and importance of both STEM and STEM education.

There is often expertise within communities that has the potential to contribute to school plans for and enactment of STEM education. As noted: *Community involvement – parents on P&F* [parents and friends association] *are scientists so keen to make science a priority* (WP15) in the school and for their children. Not only should the schools engage with the community, but teachers should *contextualise the curriculum* [in order to] – *connect to the community* (TS8). At least one participant said that the curriculum is sufficiently flexible to enable teachers to *link curriculum to their* [the students'] *chosen careers (mostly farming)* (WS2) and to address the perception in the community that STEM subjects are not important. This same participant was keen to *work with students + parents to see the need for an education past basic reading, writing & numeracy,* to contribute to positive aspirations for further education and future careers.

As suggested previously, exposing students to industries where STEM subjects are essential was deemed effective for motivating students to study these subjects and to realise their importance to future careers, for example, through taking children on excursions to local industries. Inviting people, including parents who are scientists for example, or involved in STEM careers, was identified as another strategy for enhancing student motivation and/or aspirations in STEM: *I have invited young scientists, CSIRO STEM department people to run sessions at our School* (TS6).

Finally, support for STEM teaching and learning was perceived to exist in the community as well, and participants felt it was important for RRR teachers in particular to *seek external help from the community* (WP13) and ensuring that teachers raise community awareness and acceptance of *project based learning….as valuable* (WP5) and secure their involvement by getting *the narrative right – linking STEM to community* (TS10).

Discussion

The responses of participants to the four questions posed to them prior to participating in the STEMCrAfT project revealed close synergies with the literature in STEM education and within the RRR education context. In addition, participants suggested strategies they believed would address the issues teachers face and enhance the quality of STEM teaching and learning, particularly in their own contexts. Their strategies encompassed both 'tried and true' tactics which had helped them, and those that both they and other teachers in RRR contexts would benefit from. Importantly, at the heart of these strategies was the school principal who was seen to be the best placed to build both structures and processes for enhancing teacher quality and minimising and/or compensating for teacher isolation (Du Plessis, Carroll & Gillies, 2014). While recommendations from the TEMAG report (2014) identified strategies for improving teacher practices, including a focus on strategic recruitment of staff with a commitment to people and place, the importance of such systemic and systematic approach to recruiting, supporting and retaining STEM teachers to teach in RRR contexts was not evident in the strategies suggested by participants. Rather the participants focussed more on what they perceived would assist them in improving their own practice, on a day to day basis.

The key issues that arose from the data related to the quality and availability of support and resources for teachers (Robinson, Hohepa & Lloyd, 2009) teaching STEM subjects; the time available for teachers (Merritt, 2017) to focus on their own and their colleagues' capacity to teach STEM effectively (Hobbs, 2013); and student and community/parental engagement and understanding of the importance of STEM education (Education Council, 2015). The solutions to almost all of these issues were perceived as being within the purview of the school principal and school leadership (Halsey, 2018). This is contrary to other research that found that teachers tended to locate the source of students' problems outside of the influence of the school – a tendency that Beswick et al. (2019) connected with teachers' lack of efficacy in relation to effecting change. The fact that the teachers in this study located responsibility for the issues they perceived within the school, albeit with the leadership rather than with themselves as teachers, provides some reason for optimism. It points to teachers being cognisant of ways in which issues affecting STEM teaching and learning can be addressed at the school level.

Leadership (for example, principal and discipline leader) within the school was perceived as being pivotal to addressing the issues related to STEM teaching. As Halsey (2018) summarized previously, participants' responses indicated that effective leaders are able to assist, enable and/or lead staffing and timetabling arrangements to allow collaborative planning and mentoring. As evident in the literature, the role of leaders in recognising the importance of ongoing professional learning and supporting and resourcing staff attendance was recognised by participants as essential for RRR contexts (Handal et al., 2013). This is of key importance due to the nature of the teachers currently staffing such schools which often includes staff who need support and/or upskilling of their STEM expertise (Hobbs, 2013).

In order to enthuse and engage students in STEM learning, participants highlighted the need for schools to be staffed with teachers who are themselves enthused and engaged, appropriately qualified and capable of teaching STEM subjects (Hobbs et al., 2018). They confirmed that there is a dearth of teachers with experience and expertise to teach STEM in RRR contexts, while there is a high proportion of less experienced, first-year out and/or out-of-field teachers. Such teachers require support as they become familiar with the curriculum (both content knowledge and pedagogical content knowledge), the school and being part of the profession. Aligned with advice provided by Timms et al. (2018), participants noted that any strategies aimed at building teacher capacity in the teaching of STEM should promote structured and collaborative planning at the local level, have an inter and intra-school focus straddling primary through to secondary, and have targeted professional learning formally timetabled into school planning. STEM teachers (science, mathematics, digital/design technologies) deserve appropriate ongoing support in the form of time (to plan, participate in PL, work collaboratively, etc.), mentoring and opportunities to network. Without such systematic support, teachers are unlikely to develop the confidence, capacity and enthusiasm to teach these subjects well, thereby impacting upon their students' learning and interest in continuing to study STEM subjects.

As teachers' professional isolation in some RRR contexts impacts upon them developing the capacity to teach effectively, leaders need to create ways to minimise and/or compensate for this isolation. Suggested solutions to compensate for such seclusion are resource intensive – either regularly enabling teachers to meet physically (bring the teacher to the learning centre or vice versa) or invest in effective information and communication technologies (ICT) that promote collaboration. There was a proviso to the ICT solutions suggested, as teachers in very remote locations suffer from a lack of robustness/reliability of the infrastructure (hardware, software, internet access, etc.) (Halsey, 2018) and potentially teacher capability to use them.

Students' earlier experiences of learning and poorly developed literacy and numeracy skills were perceived to limit their ability to understand later quite complex concepts in STEM. If this "diversity of readiness of students" (Sullivan, 2011, p. 40) across grade levels remains unattended to, participants emphasised that students will be ill-equipped with the knowledge that forms the basis for future mathematics and science understanding. As a result they may well disengage and not continue with higher levels of study. Participants in this research felt that because of the earlier inadequacies in many of their students' education, teachers were unable to achieve what McCarthy et al. (2018) suggested is essential, that is to challenge or extend their learning. Interestingly, contrary to previous research (e.g., Cuervo & Acquaro, 2018; Sullivan, 2011; Watson et al., 2017), none of the participants made any suggestion that teachers in RRR schools held lower expectations of their students than they may have of urban-educated students.

The importance of shared understandings amongst the school and broader community in supporting STEM initiatives and student learning in STEM subjects, was emphasised in participant responses, confirming arguments posed previously by Steyn and du Plessis (2007). Participants highlighted the need to improve the profile of STEM and awareness of the importance and relevance of STEM education within RRR communities (Roberts, 2018; Timms et al., 2018). They suggested that the community did not understand the nature of, or the importance of STEM learning to modern rural industries or future needs. As argued previously by Roberts (2014) and Timms et al. (2018), participants noted that one of their roles was to better contextualise the curriculum and engage with the community to leverage support for STEM pedagogies such as project-based learning.

Knowledge of or preference for farther-reaching strategies focussing on systemic educational or societal responses for addressing the issues relevant to STEM education in RRR contexts was not evident in the participants' responses. Rather, participants tended to focus on what they saw as within the influence of the teacher, the students, and the school within which they taught. None of the participants referred to any national narrative around STEM learning (e.g., OCS, 2010, 2012) or identified any national or state-based policies or initiatives driven by their education system (e.g., financial incentives; desirable placement [Reid et al., 2010]) that might be potentially useful for driving STEM learning or quality teaching or addressing entrenched issues such as students' disengagement and/or preparedness. This speaks to a disconnect between the practice or profession of teaching and the emerging research and/or policy position of Australia more widely.

Another interesting absence in the responses was any reference to STEM education being anything more than quality teaching and effective learning within individual STEM disciplines (e.g., science; mathematics). As discussed, effective learning of any of the individual STEM curriculum areas is perceived to be underpinned by two things. First an interdisciplinary and applied approach to teaching, that is the integration of one or more of the disciplines (Honey et al., 2014), and secondly, the application of the knowledge and skills learned through study of these areas. Given that the participants focussed on the inadequacy of the teaching of individual subjects, it can be assumed that any suggestion of extending the remit of these teachers into such problem and inquiry-based areas as advocated by Hobbs et al. (2018) is moot.

Conclusion

In conclusion, the study both confirmed and extended the research relating to STEM education in RRR contexts. While it confirmed that teachers of STEM subjects in RRR schools are very often inexperienced and/or teaching out of field, it has also provided us with a greater understanding of the strategies that teachers in RRR contexts implement in the light of such constraints. Participants recognised that students' needs and their capacity as teachers to address them, were significant hurdles to their ability to teach STEM subjects effectively. Student-centred and flexible pedagogies emerged as key to ameliorating these issues in RRR schools.

Teachers were identified as responsible for ensuring that their STEM subjects were both engaging for students and that they had the capacity to study these disciplines. They achieved this through providing appropriate learning support and engaging, relevant and challenging lessons. In addition, participants associated teacher engagement with student engagement; both being essential to effective STEM learning. Enthusiastic teachers who draw upon their own passions and interests in STEM to inform their teaching generate students who are motivated and engaged in STEM learning. These outcomes speak to the importance of targeted professional learning and ongoing mentoring of teachers.

The role of the principal was confirmed as being significant in enabling teachers to teach in these ways. In summary, it is their support and advocacy which facilitates teachers to develop their capability to teach STEM subjects through the provision of ongoing professional learning, mentoring and networking opportunities. Of equal importance is their role in providing appropriate resources including structural (timetabling) and infrastructure (information and communication technologies) in support of teacher learning and practice.

A significant contribution to the literature is the extent to which teachers perceived the school community as contributing to effective STEM learning. Participants highlighted the importance of incorporating teaching and learning approaches that are relevant to context and conducive to future learning and employment. Related to this is the necessity for teachers to view the Australian Curriculum as a guide which can be modified and enhanced to cater for community contexts, needs, interests and expertise. Constructing opportunities for involving community members in the learning process and schooling more broadly was identified as important. Drawing upon existing community expertise and networks in STEM to contribute to enhanced understandings of the importance of STEM for the future of the whole community, was viewed as critical for effective STEM learning.

The research highlighted the need for further research in two areas. Firstly, there is a need to identify ways in which teachers can work with the curriculum to effectively contextualise STEM learning for RRR settings. A second focus is the exploration of ways in which schools can engage the community authentically in both curriculum development and STEM education. In addition, how these partnerships could contribute to increasing teachers' capability to teach STEM effectively and with relevance and passion, irrespective of their experience and qualifications.

Finally, the participants who responded to the four questions that are the focus of this paper, subsequently participated in the STEMCrAfT project. Through their participation in the project, teachers with expertise and experience in teaching STEM subjects (science and mathematics in particular) contributed to the development of a resource that was then enhanced through the contributions of non-expert teachers of STEM. The resultant framework aimed to assist non-expert teachers in RR context through contributing to their ability to plan and select resources appropriate to their teaching context and their students' needs. It also mitigates against the impact of teachers of STEM who are time-poor, who may themselves be inexperienced or unqualified to teach STEM and without access to mentors on site. The framework that eventuated was experienced by those who developed, subsequently reviewed and/or used it, as very useful in capturing the expertise of STEM teachers. As such it enables out-of-field teachers, teaching in RRR contexts access to important teacher knowledge and skills, expertise that our participants indicated is often lacking in those areas.

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RESEARCH REPORT

Investigating Female Students' Stem-Related Attitudes, Engagement and Work-Intentions When Involved in a University Workshop Initiative

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Abstract: *Encouraging females to engage in and pursue Science, Technology, Engineering and Mathematics (STEM) education and vocations are key priorities for stakeholders and primary aims of the Australian Government-funded STEM in Situ (WISE 2016-18) project. Using a researcher-designed student survey by two of the authors, this article reports on the STEM-related attitudes, engagement and vocational intentions of female students involved in the project. The research survey developed for the project collected data in 2017-8 from 221 female students in Years 5-9 (11 to 16 years of age) from various public schools in Australia. Factor analytic and repeated measures t-tests data analysis techniques were used to explore the factor structure of the survey items and to examine students' STEM-related attitudes, engagement and future work intentions both before and after their participation in the STEM in Situ project. The findings highlight the outcomes of the STEM in Situ workshops upon female students attitudes and engagements with STEM careers. The findings have the potential to inform future policies related to STEM interventions for young women.*

Keywords: STEM, integration, iSTEM, integrated STEM, elementary STEM

Background

Science, Technology, Engineering and Mathematics (STEM) education has been described as a global education reform movement (GERM), fuelled in part by concerns about the capacity of various countries to innovate, compete globally and address forecasted shortages in human capital (Carter, 2018). Similar to other countries, concerns about these issues have been voiced in Australia. For instance, Marginson, Tytler, Freeman and Roberts (2013) stated that " In world terms, Australia is positioned not far below the top group but lacks the national urgency found in the United States, East Asia and much of Western Europe, and runs the risk of being left behind" (p. 12). Frequently, an economic imperative has been emphasised in discussions about the importance of STEM education, especially in policy documents and other-related literature (Office of the Chief Scientist, 2016; Price Waterhouse Coopers, 2015). Such an economic imperative refers to supply and demand of workers, and the skills shortfall of STEM-related occupations (Archer et al., 2013). This is reinforced by forecasts that STEM employment will grow 50% faster than other jobs with considerable growth in professional, scientific and health care roles (Hobbs, Clark, & Plant, 2018). Beyond an economic imperative, it could be argued that STEM-related literacies are also important in terms of a social imperative, with implications for possible innovation that may help address significant challenges such as climate change, an over-dependence on fossil fuels, and biodiversity loss.

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The term “STEM Education” itself is a contested notion, with several (sometimes conflicting) definitions and ways of being operationalised. Portz (2015) even goes so far to say that STEM education has an “identity crisis” (p. 2). Although there are differences in how STEM education has been defined, in the literature at least, there are some commonalities in its conceptualisation. For example, Radloff and Guzey (2016) identified three common features in the research. First, there is an emphasis on the interconnected nature of disciplines.. An example of such research is that of Vasquez (2015), who conceptualised STEM education on a continuum from a discrete disciplinary approach (akin to S-T-E-M) towards a more integrated, trans-disciplinary approach at the opposite end of this spectrum (STEM). According to Vasquez (2015), genuinely trans-disciplinary STEM education requires that students undertake real world-problems and apply knowledge and skills from different STEM disciplines. The second consistency that Radloff and Guzey discussed was the connectivity emphasised among school communities and industry and the focus on generic competences (e.g., problem solving, working in teams, creativity). The third commonality is the notion that STEM education is commonly tailored to stakeholders’ needs and contexts. Awareness of context means schools are operationalising STEM to meet the needs of students and give them access to innovative technologies and specific educator expertise in schools.

As nations strive to reform the delivery and relevance of STEM education, a consistent and ongoing challenge is addressing the underrepresentation of particular student groups. There are concerns about the engagement of females in STEM. There is evidence to indicate the engagement, participation and performance of females in STEM is in decline both at tertiary and senior secondary levels of education (Kennedy, Lyons, & Quinn, 2014; Timms, Moyle, Weldon, & Mitchell, 2018; Weber, 2012). As noted by several researchers in this field, without a diverse female-targeted STEM pipeline attempts to change this situation will be marginal (Marginson et al., 2013; Tytler, Osborne, Williams, Tytler & Clark, 2008; Watt, 2016). A pipeline implies a flow of engaged students in primary school leading to participation of students in secondary and senior-secondary STEM subjects. This in turn means skilled students are retained into post-school STEM learning, including into teacher education courses and also onto STEM-related careers. A longer-term key benefit of a female STEM pipeline is building the flow of STEM-literate parents who pass on curiosity and engagement in STEM to the next generation of women.

Many studies have highlighted the role of identity in STEM learning and the need to address this problem by exposing female students to role models, collaborative STEM experiences, opportunities that match their interests, and mentoring that encourages STEM identities (Archer et al., 2013; Hobbs et al., 2017; Timms et al., 2018). How an individual sees him or her selfherself has been shown to effect and influence general academic engagement (Matthews, Banerjee, & Lauermann, 2014), performance in specific disciplines (Kozoll & Osbourne, 2004), and to the pursuit of future careers (Perez, Cromley, & Kaplan, 2013).

Polman and Miller (2010) described STEM identity as the ability of individuals to see themselves as the kind of people who could be legitimate participants in STEM through their interests, abilities, race, gender, and cultures. Other researchers note the role of experts or parents in influencing positive STEM outcomes (Archer et al., 2010; Nadelson et al., 2013). Different gender expectations also build identity when it comes to STEM and these expectations contribute to an identity that sees engaging in STEM as “clever and brainy” and not “caring or nurturing,” the latter being traits that are typically seen to be more appealing to girls (Wang & Degol, 2013).

Recent research on STEM identities has highlighted the importance of STEM identity in female students and the development of that identity into future STEM careers. Of interest is the importance of social identity amongst high achieving female students. As Kim, Sinatra, and Seyranian (2018) noted:

> Many young girls do not feel positive about their own abilities or their potential for success in STEM. Social identity theory suggests that individuals are driven by a need for positive self-esteem. STEM fields are making it challenging for women to see themselves in a positive light. They are, in fact, often doing the opposite and diminishing positive self-esteem. This is even the case for young women who earn good grades in STEM courses or are deemed gifted. (p. 613)

To identify with STEM, and thus pursue studies and careers in STEM, the STEM learning environment needs to convey messages of welcome for young women. Evidence exists that where programmes encourage interest, positive identity and attitudes towards STEM, positive changes in terms of engagement and interest can be developed by young females (Metcalf, 2013; Naizer, Hawthorne, & Henley, 2014). The influence of peers has also been found to be important in intentions to pursue STEM careers (Leaper, Farkas, & Brown, 2012). When young women were encouraged to be part of a STEM "in-group", engagement and interest also grew (Reid & Roberts, 2006). These studies indicate that engaging in STEM for young women is related to social identity as well as self-identity.

As part of any reform agenda, stakeholders must address cultural, institutional and organisational factors that discourage girls and women from studying STEM and choosing careers in those fields, particularly in areas of significant under-representation such as physics and engineering. Attempting to ascertain the benefits of interventions that address some of these systemic barriers, the researchers in this study designed a program targeting secondary female students (11-16 years of age). This involved a series of workshops and mentoring activities that provided the female students with hands-on experiences in STEM-related activities and exposure to the creative possibilities of such disciplines.

Context of the Study

The STEM in Situ Project

The Women in STEM (WISE)- *STEM in Situ* project was a nationally funded Australian Government initiative which, over a two-year period, introduced 221 female students aged between 11 and 16 years (grades years 5-9), including those from low socio-economic and Indigenous backgrounds, to STEM workshops in technology-rich facilities at a local university. The female students came from twelve schools in the northern and western suburbs of a major city in Australia, up to 25 kilometres distance from the university.

Emphasizing STEM skills in creativity, design, entrepreneurship, problem solving, adaptive thinking, digital literacy and technology-confidence, the project attempted to build the students' STEM self-identity so they could be creators of their own futures. Over four workshop days per school term (totalling of sixteen days) the students explored STEM skills and knowledge across many industries as diverse as: fashion, virtual reality, additive manufacturing, nanotechnology and robotics; in emerging growth industries; and in entrepreneurial opportunities. This involved interactive talks and maker workshops. The female students also had opportunities to undertake group work with tertiary-employed female STEM leaders. Within the workshops, the female students were in groups of mixed ages, abilities and schools. Workshop leaders, technicians and mentors were unaware of the backgrounds or previous STEM understandings of the female students prior to workshop participation.

The STEMTAS Survey

The STEM *in Situ* project utilized the STEMTAS survey, which was adapted from the

Mathematics and Technology Attitudes Scale (MTAS) developed by Pierce, Stacey and Barkatsas (2007). The survey has been used extensively to examine the role of the affective domain in learning mathematics with technology. According to the scale developers, MTAS can be used in schools to track changes in the attitudes and engagement of students in their learning of mathematics. It was based on the work of McLeod (1992), who described the affective domain as being composed of three major constructs - *beliefs, attitudes,* and *emotions* – with each representing "increased levels of affective involvement, decreased levels of cognitive involvement, increasing levels of intensity of response, and decreasing levels of response stability" (p. 579).

Student engagement is an important goal for education (Marks, 2000). Fredricks, Blumenfeld, and Paris (2004) note that school engagement is a concept that is malleable, responsive to contextual features and amenable to environmental change. They claim that engagement is a multidimensional concept or a "meta" construct. They proposed the following three dimensions: behavioural engagement, which draws on student participation, emotional engagement, encompassing both positive and negative reactions to staff and the school in general, and cognitive engagement, which draws on the principle of students making an investment in learning (Fredricks et al., 2004). Only two of the dimensions of this framework, that is, behavioural engagement and emotional engagement were incorporated into the STEMTAS instrument used in this study. The cognitive engagement dimension was not investigated in this study.

Measuring Intentions and Attitudes to STEM-Related Future Learning and Careers

Of key interest to the researchers was the female students' attitudes and intentions to participate in STEM-related learning and careers as a result of the STEM *in Situ* workshops. Research examining the link between intention and behaviour has its origins in Expectancy-Value Theory (EVT) and is commonly used to examine the beliefs of why individuals choose one behaviour over another (Porter & Lawler, 1968). Intentions are formed by several beliefs that represent the perceptions that people have about a behaviour including its likely consequences, the normative expectations of others, and the likely barriers of performing a particular behaviour (Ajzen, 2005). A salient predictor of intentions (and future behaviour) is attitude (Kraft, Rise, Sutton & Røysamb, 2005). Attitude is a key human motivator and it can be viewed as a construct that influences the intensity and direction of a behaviour (Ajzen, 2005). Considering the former, eliciting students' intentions and attitudes to future careers in STEM-related fields has the potential to offer insights into participants' desired future pathways and trajectories.

Research Methods

Participants

The participants in the project were 221 (years 5-9) female students from government schools in a major city in Australia. All of the female students were aged between 11 and 16 years and were in primary and secondary schools in the western and northern suburbs of Melbourne. The female students attended schools that were geographically located in a range of socio-economic regions as measured by Socio-Economic Indexes for Areas (SEIFA) index. The schools were located in local council regions ranging between 951 deciles (relative disadvantage) to 1059 deciles (relative advantage) on the SEIFA scale (Australian Bureau of Statistics, 2018).

The guidelines for participation in the STEM workshops did not specify how female students at each school were to be selected for participation. As a result, participation in the workshops was decided by the administrators and the teachers at each school. Some participating schools sent all the female students from a particular grade level; a number of schools sent female students who had shown some interest in STEM determined by teacher observation; and some schools decided to use an expression of interest strategy based selection on a "first come basis" of participation.

Data Collection Instrument

A survey, which included the STEMTAS and the Attitudes to Further Learning in STEM and STEM Career survey, was administered at the beginning of the first day of workshops and again on the last day of workshops, which spanned a period of two to four weeks per school group. The survey was completed anonymously, and students and their parents were made aware of the purpose of the survey via ethics and school consents. Sixteen workshop days were held each year
The research study used a 36-item research instrument consisting of two sections:

(1) *The STEM Technology Attitudes Survey (STEMTAS).*

A Likert-type scoring format was used for each of five subscales (items 1-20):

(i) STEM confidence [STEMC].
(ii) Confidence with digital technology [TC].
(iii) Attitude to learning STEM with digital technology [STEMT].
(iv) Affective engagement [AE].
(v) Behavioral engagement [BE].

Students were asked to indicate the extent of their agreement with each statement on a five-point Likert scale from strongly agree to strongly disagree (scored from 5 to 1) for sub scales (i)-(iv). A different but similar response set was used for the BE subscale. Students are asked to indicate the frequency of occurrence of different behaviors. Again, a five-point system was used – nearly always, usually, about half of the time, occasionally, hardly ever (scored from 5 to 1).

The STEMTAS subscales can be defined as follows: *STEM Confidence* [STEMC]: students' perception of their ability to attain good results and their assurance that they can handle difficulties in STEM subjects; *Confidence with Digital Technology* [TC]: technology confidence as evidenced by students who feel self-assured in operating computers, believe they can master digital technology procedures required of them, are more sure of their answers when supported by a computer, and in cases of mistakes in digital technology work are confident of resolving the problem themselves; *Attitudes to Learning STEM with Digital Technology* (STEMT): students believe that the use of digital technology interfaces enhances STEM learning by the provision of many examples, find note-making helpful to augment screen based information; *Affective Engagement* [AE]: how students feel about mathematics and *Behavioral Engagement* [BE]: how students behave in learning STEM-related subjects.

(2) *The Attitudes to Further Learning in STEM and Intentions of a STEM Career survey*

A key aim of Section 2 (items 21-36) of the survey instrument was to elicit students' intentions about STEM-related future learning and careers. Semantic differentials using five-point scales were used to elicit *Attitudes to further learning in STEM* (e.g., I believe further learning in STEM will be [useless-worthwhile]). *Attitudes to a STEM career* were also elicited (e.g., I believe a STEM career in the future will be [bad for me-good for me]). Experiential items (how it feels to perform the behaviour [e.g., studying further learning in STEM will be unpleasant/pleasant]) and instrumental items (whether the behaviour achieves something [e.g., I believe further learning in STEM will be useless/worthwhile]) were included. Also, Likert-type format was used to elicit participants' *Intentions to study STEM at university* and *Intentions to work in a STEM-related field in the future* (1-strongly disagree to 5-strongly agree).

Data analysis

An initial data screening was carried out to test for univariate normality, multivariate outliers (Mahalanobis' distance criterion), homogeneity of variance-covariance matrices (using Box's M tests) and multicollinearity and singularity (tested in the MANOVA analysis). Descriptive statistics normality tests (normal probability plot, detrended normal plot, Kolmogorov-Smirnov statistic with a Lilliefors significance level, Shapiro-Wilks statistic, skewness and kurtosis) showed that assumptions of univariate normality were not violated (Tabachnick & Fidell, 1996). Univariate and multivariate distributions were examined for potential outliers. As a result, four students were eliminated from the consequent analyses, resulting in a final sample size of 217 students. Box's M Test of homogeneity of the variance-covariance matrices (which tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups) was not significant at the 0.001 alpha level and we therefore concluded that homogeneity of variance may be assumed (Tabachnick & Fidell, 1996). The items in each of the two sections of the survey were subjected to an Exploratory Factor Analysis (EFA). Reliability tests were also conducted and a repeated measures (paired t-test) was used to investigate statistically significant differences between the pretest and the posttest variables.

Exploratory Factor Analysis

(1) STEMTAS (items 1-20)

A Principal Component Analysis (PCA) with a Varimax rotation from students' pretest responses to the 20 Section 1 (STEMTAS) survey items indicated that the data satisfied the underlying assumptions of the factor analysis (Table 1). The data revealed that together, the five factors (each with eigenvalue greater than 1) explained 62.1% of the variance, with 32.5% attributed to the first factor – *STEM confidence*. Further, according to Coakes and Steed (1999), if the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy is greater than 0.6 and the Bartlett's test of sphericity (BTS) is significant then factorability of the correlation matrix is assumed. A matrix that is factorable should include several sizable correlations. The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy in this study is greater than 0.81 and the Bartlett's test of sphericity (BTS) is significant at 0.001 level, so factorability of the correlation matrix has been assumed. Reliability analysis yield satisfactory Cronbach's alpha values for each factor: Factor 1, 0.97; Factor 2, 0.93; Factor 3, 0.88; Factor 4, 0.80 and Factor 5, 0.70. These values indicate a moderate to strong degree of internal consistency in each factor (Hair, Black, Babin and Anderson, 2014).

Table 1. *Rotated Component Matrix (items 1-20). Extraction method: Principal Component Analysis, Rotation method: Varimax with Kaiser Normalization*

	Component				
	1	2	3	4	5
Q9. I have a 'STEM' mind	.767				
Q10. Overall, I can get good results in STEM	.753				
Q16. I get a sense of satisfaction when I solve STEM problems	.720				
Q1.1 I know I can handle difficulties in STEM	.707				
Q12. I am confident with STEM	.613				
Q19. STEM is more interesting when using information/digital technology		.863			
Q17. I like using information/digital technology for STEM		.750			
Q18. Using information/digital technology in STEM is worth the extra effort		.674			
Q20. Information/digital technology help me learn STEM better		.642			
Q7. I can fix a lot of information/digital technology problems			.760		
Q5. I am good at using information/digital technology			.733		
Q6. I am good at using things like ipods, ipads, bluetooth, mobile phones and the internet			.727		
Q4. If I can't do a problem, I keep trying different ideas				.761	
Q3. If I make mistakes, I work until I have corrected them				.752	
Q1. I concentrate hard in STEM				.632	
Q2. I try to answer questions the teacher asks				.546	
Q14. In STEM you get rewards for your effort					.624
Q15. Learning STEM is enjoyable					.556
Q13. I am interested to learn new things in STEM					.472

The naming of the *five factors* was guided by the relevant literature and the nature of the questionnaire items associated with each factor. This resulted in the following five factors (F1-F5):

- F1: *STEM Confidence* (STEMC)
- F2: *Attitudes to Learning STEM with Digital Technology* (STEMT)
- F3: *Confidence with Digital Technology* (TC)
- F4: *Behavioral Engagement* (BE)
- F5: *Affective Engagement* (AE)

The first factor (STEMC) consisted of five items, which examined students' *STEM confidence*. One item from the affective engagement (AE) subscale was loaded with this factor. A plausible explanation is that it is a sample-specific outcome. The 2nd factor (STEMLT) consisted of four items, which examined students' *Attitudes to Learning STEM with Digital Technology.* The 3rd factor consisted of four items, which examined students' *Confidence with Digital Technology* (TC). Factor 5 consisted of three items, which examined students' *Behavioral Engagement* (BE).

(2) STEM-related intentions and attitudes to future learning and careers (items 21-36)

A Maximum Likelihood extraction method and a Varimax rotation (Tabachnick & Fidell, (1996) was used in the survey items 21-36 (Table 2). Two factors (each with eigenvalue greater than 1) explained 69.98% of the variance, with 54.65% attributed to the first factor – *Intentions to continue a STEM-related trajectory*. For this part of the study, the KMO = 0.89 and BTS was significant (*p*<0.01), so factorability of the correlation matrix is assumed. Cronbach's alpha indicated a strong degree of internal consistency in each factor: Factor 1, 0.96 and Factor 2, 0.84.

Table 2 . *Rotated Factor Matrix (items 21-36). Extraction Method: Maximum Likelihood, Rotation Method: Varimax with Kaiser Normalization.*

	Factor	
	1	2
Q36. I plan to work in a STEM-related field in the future	.934	
Q33. I expect to work in a STEM-related field in the future	.909	
Q31. I intend to study a STEM-related degree at university	.909	
Q35. I intend to work in a STEM-related field in the future	.904	
Q32. I plan to study a STEM-related degree at university	.891	
Q29. I expect to study a STEM-related degree at university	.883	
Q34. I want to work in a STEM-related field in the future	.847	
Q30. I want to study a STEM-related degree at university	.812	
Q27. A STEM career in the future will be (Unpleasant/Pleasant)		.896
Q28. I believe a STEM career in the future will be (Unenjoyable/Enjoyable)		.851
Q24. I believe further learning in STEM will be (Unenjoyable/Enjoyable)		.569
Q23. Studying further learning in STEM will be (Unpleasant/Pleasant)		.557
Q26. I believe a STEM career in the future will be (Useless/Worthwhile)		.550

As with Section 1, the naming of the two factors was guided by relevant literature and the nature of the questionnaire items associated with each factor:

- F1: *Intentions to continue a STEM-related trajectory* (STEMIT)

Shown in Table 2, the first factor (STEMIT) consisted of eight items, eliciting students' intentions to continue a STEM-related trajectory, inclusive of STEM study and/or pathways. This measure is reflective of students' intentions to stay in the so-called 'STEM pipeline'.

- F2: *Attitude to continue a STEM-related trajectory* (STEMAT)

The second factor (STEMAT) included five items, examining students' attitude to continuing along a STEM pathway. Such an attitude is an overall positive evaluation of future STEM study and work options.

Repeated Measures (Paired t-test)

The existence of statistically significant differences on the sample's pretest and the posttest scores was investigated by a Wilcoxon signed-rank repeated measures t-test (Coakes & Steed, 1996). By checking the t-values and the two-tail significance, statistically significant differences were found for the following items in the STEMTAS section of the survey (items 1-20):

- I try to answer questions the teacher asks [z = -2.191, p < .05]
- I am good at using information/digital technology [z = -2.227, p < .05]
- I can fix a lot of information/digital technology problems [z = -3.904, p < .05
- Overall, I get good results in STEM [z = - 2.502, p < .05]

- I like using information/digital technology for STEM [z = - 1.990, p < .01]
- STEM is more interesting when using information/digital technology [z = -2.845, p < .01]
- Information/digital technology help me learn STEM better [z = -2.258, p < .05]

Statistically significant differences in the means of pretest and posttest scores were found for all STEMT items, 2 *Confidence with Technology* items and 1 *affective engagement* item. No statistically significant differences were found for any of the STEM-related intentions and attitudes to future learning and careers items. The pre-directional responses of the pretest and the posttest mean scores for the STEMTAS items are shown in Figure 1. For most pretest items, the mean scores were greater than 4.0 and most posttest items the mean scores were greater than 4.2. The mean pretest score was 4.2, and the mean posttest score was 4.3. For 90% of the items the mean scores for the posttest were greater than mean scores for the pretest. The pretest mean scores or items 6 and 13 were greater than their posttest mean scores. Item 7 had the smallest mean score and item 13 the largest mean score.

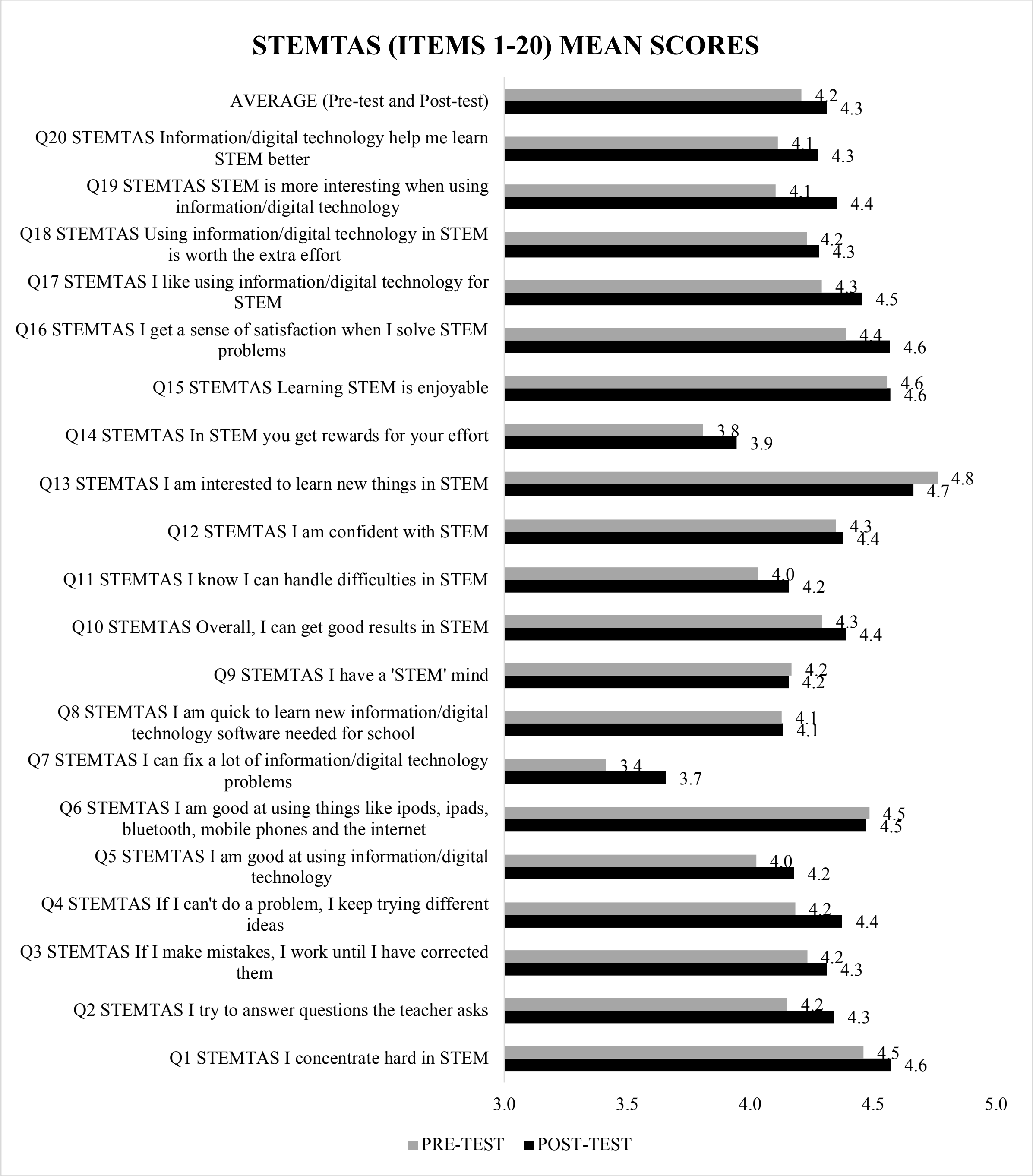

Figure 1. STEMTAS pretest and posttest mean scores.

Overall, the pre and posttest averages for the items in Section 2 (Figure 2) were equal. Examining this data further, approximately 37% of the items in this part of the study indicated that posttest scores were slightly lower (none were statistically significantly lower) than pretest measuring. Approximately the same number of items (≈37%) indicated no change between pre and post testing. Conversely, 25% of items were higher in posttest measures than the pretest examination, although yet again, none of the t-tests indicated significantly different results (*p*>.05).

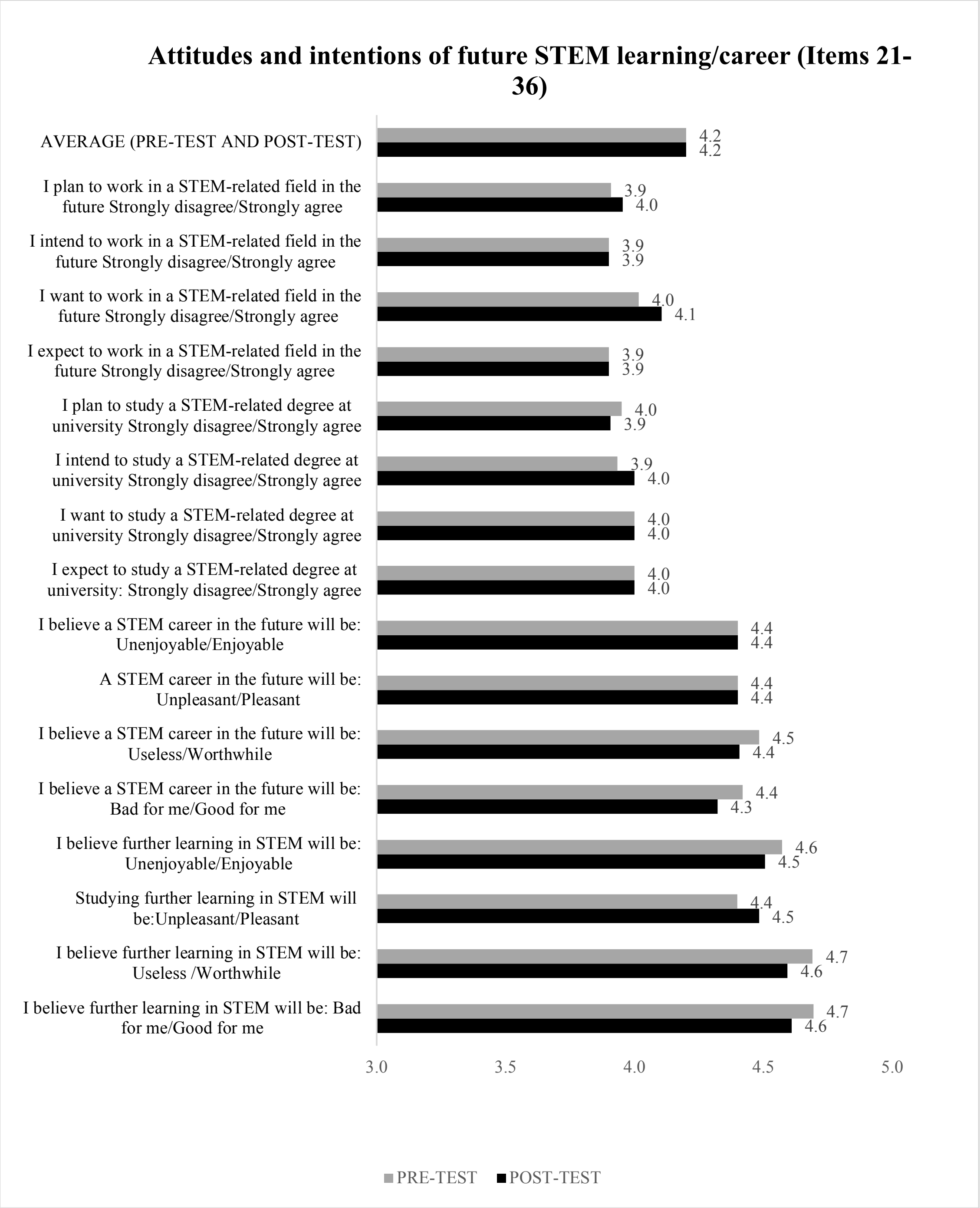

Figure 2. Pretest and posttest scores of STEM-related attitudes to future learning and intentions of STEM careers.

Discussion

An essential element of the STEM discourse internationally is how to cater effectively for the needs and barriers facing under-represented groups in their study of, and vocational participation in STEM. In male dominated areas of STEM (e.g. physics, engineering, digital technologies), reform agendas need to challenge cultural, institutional and organisational factors that discourage females from studying STEM and choosing careers in those fields. Student experiences that challenge covert and overt norms about who belongs and who should participate STEM disciplines is crucial, and hence the program of interest in this study was a modest attempt to challenge such assumptions. Aligning with the research discussed earlier about the importance of identity in STEM learning (Kozoll & Osbourne, 2004; Matthews et al., 2014), STEM *in-Situ* was designed to expose female students to role models, collaborative STEM experiences, opportunities that match their interests, and mentoring that encourages STEM identities. Salient elements of such identities are inclusive of students'- beliefs, attitudes and intentions to continue (or discontinue) their STEM pathways.

The development of the STEMTAS instrument was based on the assumption that it would measure affective changes in participants. The results of the STEMTAS items (items 1-20) indicated that statistically significant differences in the means of pretest and posttest were found for all STEMT items, 2 Confidence with Technology items and 1 Affective engagement item. It appears that the students' attitudes to learning STEM with digital technology were impacted on positively. Such attitudes have the potential to impact students' STEM learning participation and learning outcomes although such associations need further research in this context before one could reasonable claim such relationships.

It is important to point out that this research is exploratory in nature and in a relatively early phase of development. There is the intention to validate STEMTAS by Confirmatory Factor Analysis (CFA) and Structural Equation Modelling (SEM) techniques through studies with various samples, which will include both male and female students from different countries, school sectors and cultural contexts. The results from this study provide preliminary positive confirmation of the validity and reliability of the survey.

There were no significant differences between the pretest and the posttest mean scores in Section 2: Attitudes to learning and career intentions (items 21-36) of the survey instrument. This is consistent with findings reported by Reid and Roberts (2006) in relation to pre and posttest scores in intervention programs. However, it could be argued, as Reid and Roberts suggest, the constructs of future study intentions, attitudes and STEM engagement form over a relatively long-time span. Hence, the potential to see significant differences in pre and post testing does not necessarily indicate the efficacy of the intervention. Projects such as the STEM *in Situ* initiative offer the potential for students to experience an 'episodic STEM moment'- a salient experience that students reflect on in the future as they consider their future study and work pathways. The impact of a recalled episodic STEM moment may not occur for some time, it is possible that the value of such an experience is not realised until several years into the future, potentially when the female students are making a pathway decision about their education or career.

Ideally programs such as STEM *in Situ* should complement a home and school environment that places value upon the learning of STEM knowledge and skills. Adamuti-Trache and Andres (2008) note that parents influence their children's academic choices and, in doing so have the potential to encourage them toward STEM-related subjects. Beyond parental influence, it is important for stakeholders to consider and address structural barriers, a significant challenge for educators appears to be the design and implementation of a STEM program that meets the diverse needs of students, particularly for under-represented cohorts, including females in subjects such as physics and engineering. Overall, this workshop initiative (STEM *in situ*) provided a space for participants to consider their future STEM trajectories, offering chances to collaborate with female peers who share similar aspirations. Such programs are important in promoting and fostering an environment that places value on the learning and participation of STEM education in students' lives.

Students' STEM-related beliefs, attitudes and intentions have been conceptualised in this study as salient components of their identities—as the ability of individuals to see themselves as the kind of people who could be legitimate participants in STEM through their interests, abilities, race, gender, and cultures (Polman & Miller, 2010). As noted previously, Kim etal. (2018) stated that “many young girls do not feel positive about their own abilities or their potential for success in STEM” (p. 613). While this specific project is in its infancy, there are encouraging signs that STEM *in Situ* has had positive impacts on different elements of students’ STEM literacies. Nevertheless, it is important to remember the relatively modest scope of this initiative and the need for a much larger suite of resources and programs dedicated to addressing the systemic factors that negatively impact the potential of females studying STEM and participating in related careers.

Conclusion

Evidence indicates that female engagement, participation and performance in STEM are in decline both at tertiary and senior secondary levels of schooling (Office of Chief Scientist, 2016). This study investigated STEM-related attitudes, engagement and vocational intentions of secondary female students. The study examined the responses of female students who participated in the STEM *in Situ* (WISE 2016-18) project. The aims of the research study were to measure the factorial structure of the research survey used in this research and to examine differences between students’ pretest and posttest attitudes toward STEM, STEM confidence, engagement with STEM and their STEM-related future learning and careers. The study indicates there were not significant differences in many of the pre and posttest results, but there were significant differences regarding students’ use and confidence with digital technologies. However, constructs of future study intentions, attitudes and STEM engagement form over a relatively long-time span. Hence, the potential to see significant differences does not necessarily indicate the full potential of the intervention. Programs such as STEM *in situ* do provide the opportunity for students to experience episodic STEM moments, now or into the future. Such intervention environments have the capacity to promote and foster engagement and interest in STEM and should be considered in future STEM initiatives to change longer-term outcomes.

A second longer term consideration is the development of school/university partnerships to promote female engagement and future intentions in STEM. The STEM *in Situ* model allowed stakeholders (e.g., technicians, pre and in-service teachers, students, mentors) to come together and engage in STEM workshops as a collective team in a university/school partnership. This opportunity indicates the potential for future adoption of STEM interventions, in particular the exposure to STEM equipment and resources not utilised or available in school facilities. Such partnerships may also build longer term outcomes not measurable in this study. The importance of developing female STEM-identity and building a female STEM pipeline to achieve reform in STEM participation, engagement and long-term career aspirations are key motivators in interventions such as that described in this study. Continued support for this type of intervention has the potential to achieve long term change for the benefit of more diverse, inclusive and creative STEM spaces.

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RESEARCH REPORT

STEM and STEAM and the Spaces Between: An Overview of Education Agendas Pertaining to 'Disciplinarity' Across Three Australian States

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Abstract: *This article presents an overview of how interdisciplinary education agendas are being interpreted and enacted within three Australian states: New South Wales, Tasmania and Victoria. A comparative discussion is offered to ascertain the common and contrasting inhibitors and enablers of these agendas, specifically approaches to STEM and STEAM across the three states. Consideration is given to the priorities espoused in current State and Federal policy agendas. The article explores how disciplinary acronyms such as STEM and STEAM are being mobilised to empower or exclude particular disciplines, and how this implicates upon enactment of the three dimensions of the Australian Curriculum. By focusing on the contested spaces between these disciplines, the distinctiveness and potential of various interdisciplinary agendas can be better understood. In turn, ways of recognising, embracing and prioritising different forms of disciplinary knowledge can be identified in the spaces between disciplinary curriculum and pedagogy. These diverse ways of knowing are posited as integral to equipping young people for uncertain futures.*

Keywords: STEM, STEAM, interdisciplinarity, interdisciplinary education

'What happens between disciplines stays between disciplines': A preface for acronym extrapolation

The STEM acronym has become ubiquitous in the 21st century, with little need to remind readers that it refers to the disciplines of Science, Technology, Engineering and Mathematics. What is less well known is that the National Science Foundation in the United States of America (U.S.A.) originally coined STEM for a strategic purpose in the 1990's. Its purpose was to recognise the importance of the four STEM disciplines in the economy and as a basis for innovation (Moore, Johnson, Peters-Burton & Guzey, 2016). Further to influencing thinking about the relationship between these four disciplines, combining them into the STEM acronym also contributed to the creation of both alliances and hierarchies, which have underpinned and influenced policy and educational trends from the 1960s to the present day (Mohr-Schroeder, Cavalcanti, & Blyman, 2015). More recently, other disciplinary acronyms have emerged in scholarly literature, most notably STEAM, which seeks to emphasise the potential for the Arts to contribute powerfully to disciplinary commentary around the importance of creativity and design for innovation, entrepreneurialism and reimagined work (Costantino, 2018; Craft, 2011; Yakman, 2008; Yakman & Lee, 2012). Beyond the disciplinary alliances underpinning STEM and its mandate to respond to economic priorities (Saunders, 2009), attention continues to focus on educational reforms that ensure workforce-ready STEM graduates are a priority in tertiary education. To allow such a vision can come to fruition, it is essential that interdisciplinary education

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agendas are driven by teaching that is inspirational, meaningful and transformative for all students (Tregloan, Wise & Fountain, 2018).

The emergence of various acronyms drawing together different discipline areas serves many functions as well as dysfunctions in Australia, depending on how the particular interdisciplinary acronym is interpreted and then enacted. Discussion pertaining to the relationship between STEM and STEAM education in Australia continues to draw significant coverage across scholarly inquiry, political speech and in mainstream media. The challenges and benefits inherent to enacting agendas associated with STEM and STEAM have piqued the attention of academics, politicians and public commentators alike (Colluci-Gray et al., 2017; Colluci-Gray et al., 2019; Yakman & Lee, 2012). It can be broadly inferred from STEM and STEAM scholarly literature and commentary in Australia, that running parallel to this conversation, research and curriculum developers continue to grapple with different, disparate or conflicting interpretations of how [inter]disciplinary education unfolds in the move from theory to practice (MacDonald & Wise, 2018; Taylor, 2016). However, the question of whether such acronym grappling meaningfully shapes or distracts from a successful, inclusive and holistic education experience remains.

In school education contexts, this struggle and associated ambiguity, runs concurrent to teachers and students across the country enacting their own possibilities of what multi, cross and other prefixes for '- disciplinary' education can look like. While 'interdisciplinary' captures the broad range of combinations implied, each represents a distinct approach to combining disciplinary conditions, ranging from the additive (multidisciplinary) to the transformative (transdisciplinary) (Davies & Devlin, 2010); yet each requires clarity on their defining qualities, specific goals, approaches and conditions to succeed.

An emerging realisation is that while uncertainty around practical applications of disciplinary education acronyms poses challenges, indecision also creates problems, and problems in turn provide opportunity for reimagination and innovation (MacDonald & Wise, 2018). In the uncertain spaces, or nexus points where disciplines interrelate (whether STEM, STEAM or something else), the implications of their relationality and potential interconnections warrant further inspection.

The body of emerging literature around STEM and STEAM education posits that in order for such interdisciplinary approaches to be achieved, an understanding of the practice of STEM must first be established (Cunningham 2018; Liao, 2016; Radizwill, Benton & Moellers 2015). Recognition of the equal value associated with different ways of knowing, and an appreciation of the distinctive lenses brought to knowledge by each discipline is needed before the environments and circumstances necessary to hold interdisciplinary practices can be articulated (Marshall, 2014). Our ability to recognise the equal value and distinctiveness of disciplines is thwarted in any discipline acronym arrangement that promotes or demotes disciplines or seeks to exclude disciplinary fields.

A significant contention underpinning the commentary around STEM and STEAM is disciplinary hierarchies; inherent, often binary perspectives and/or biases, that privilege one or more disciplines over another in an interdisciplinary education context. The term "disciplinary egocentrism" describes the lack of student readiness to engage in multidisciplinary education (Paretti, 2011), however, the term can also be applied to a wide range of key education stakeholders, such as teachers, academics and indeed STEAM industry experts who are unable or unwilling to value alternative approaches to their respective discipline areas (Yoder, Bodary & Johnson, 2016).

A perspective offered by Liao (2016) compels STEM and STEAM theorists and practitioners to divert their attention from attempts to reconcile hierarchal disciplinary competition, to instead invest their attention and efforts to context and in the spaces *between* disciplines. For example, an arts-integrated approach to STEAM education, where teaching and learning concentrate on and derive from the liminal and relational 'inter-spaces' between disciplines, can open up a transdisciplinary space — a transformative space that is at once oriented between, across and beyond all disciplines (Davies & Devlin, 2010; Hobbs, Cripps-Clark & Plant, 2018; Liao 2016). If we are to consider what this dissolution of discipline hierarchy may look like in a STEM education context, Nadelson & Seifert (2017) champion the need for seamless amalgamation of content and concepts so that "knowledge and process of the specific STEM disciplines are considered simultaneously without regard for the discipline, but rather in the context of a problem, project or task" (p. 221).

Such examples are indicative of how some STEM and STEAM theorists are working to resist the distraction that discipline hierarchy arguments create for efforts to shift away from perceived arbitrariness of any particular discipline acronym. An emergent body literature is establishing the need to move beyond disciplinary politicking and instead look beyond the acronyms themselves and concentrate on their interdisciplinary enactments in context (MacDonald & Wise, 2018; Tytler, Williams, Hobbs & Anderson, 2019). Before such aspirations can be realised however, there is a need to recognise and be mindful of the myriad challenges these ongoing movements mean for teachers; the work they have already done and continue to do to enact interdisciplinary education agendas and priorities such as STEM and STEAM. In Australia, an array of intersecting national, state and education sector specific STEM education strategies (see Education Council, 2015; NSW Department of Education, 2018; Tasmanian Department of Education, 2015, 2017) have been developed, with educators investing considerable time, effort and energy in their grappling with and adoption of the vernacular inherent to these strategies in their classroom enactment of STEM education. To hurry past the already significant investment of federal and state policy think-tanks, and ongoing efforts teachers are making to achieve the visions of interdisciplinary education strategies that perpetuate the same disciplinary acronyms we might ask them to look beyond is problematic. For decades already, "educational reform in Australia has been a quagmire of political and educational agendas, with a myriad of known factors (of which change fatigue is a part) that have enhanced or hindered implementation" (Dilkes, Cunningham & Gray, 2014, p. 46). In order to avoid education reform fatigue, any shifting away from the vernacular and challenges inherent to disciplinary acronyms needs careful consideration. In order to transcend perpetuation of disciplinary acronyms, the foundations of the tensions that exist between the disciplines must be understood and reconciled, and while the acronyms at present may not well serve the interdisciplinary education 'end game', they are an integral and significant part of the education reform journey. Bearing in mind that cynical, realistic and even enthusiastic teachers suffer reform fatigue after years of rapid and continual change (Dilkes et al., 2014; Savage, 2016), it is imperative that teachers be given time, space and voice in defining the reconciliation and transcendence of disciplinary acronym perpetuation. The focus for conceptualisation and operationalisation of interdisciplinary education can then purposefully orient itself towards recognising and understanding how context and differentiation implicate enactment, Given the absence of a universally agreed-upon definition of what STEM education embraces, it can be inferred that each country establishes their own definition. In Australia, the National Strategy in STEM Education (Education Council, 2015) refers to:

> … the teaching of the disciplines within its umbrella – science, technology, engineering and mathematics – and also to a cross-disciplinary approach to teaching that increases student interest in STEM related fields and improves students' problem solving and critical analysis skills (Educational Council, 2015, p. 5).

In their literature and policy review of the challenges faced in STEM learning in Australian schools, Timms, Moyle, Weldon and Mitchell (2018) highlight both the importance of disciplinary knowledge and the need to shift the educational focus towards "the practices and ways of thinking in each discipline" (p. 21). This need to shift is emblematic of the culture of 'reform fever' (Savage,

2019) implicating upon policy enactment within out contemporary Australian education. While some policies "might give an *illusion of stability,* a wider view ultimately reveals constant motion and new beginnings" (Savage & Lewis, 2018, p. 124, emphasis in original). In integrated STEM education, there is an emphasis on "real-life contexts and the development of proto-types or models to similar authentic problem-solving or decision-making scenarios" (Fraser, Earle, Fitzallen, 2019, p. 15). Such an approach is different from traditional STEM pedagogies and cannot be pursued without significant deviations in both curricula and conventional teaching methods. The successful integration of creative arts and other disciplinary approaches in STEM teaching and learning contexts requires teachers capable of learning how to teach alternative disciplinary approaches; as well as an evidence base that justifies such (Bequette & Bequette, 2012).

The Australian Curriculum is organised into three distinct components, or dimensions, comprising three Cross-Curriculum Priorities (CCPs), seven General Capabilities (GCs) and eight Learning Areas (LAs). The Australian Curriculum, Assessment and Reporting Authority (ACARA, 2017) present the whole Australian Curriculum as a three-dimensional curriculum that "recognises the central importance of disciplinary knowledge, skills and understanding" (p. 1) inherent to LAs in relation to GCs and CCPs. The three dimensions are positioned in a non-hierarchal and interrelated structure, creating space and aspiration for a wholly mobilised and richly relational curriculum that holds integration and interconnectedness at its core. This three-dimensional interpretation offers an inter-related, rounded whole; with detail within each of the three dimensions differentiating learning areas into distinct subject/ discipline areas, and a suite of defined skills, capabilities and priorities. This vision of learning outcomes that enables discipline knowledge, skills, behaviours and dispositions to be fostered across subject-based content, general capabilities and cross-curriculum priorities is contingent upon a teachers' preparedness and capacity to enact interdisciplinary teaching (Harris & de Bruin, 2017). If teachers are to meet the challenge of equipping students "to be lifelong learners and be able to operate with confidence in a complex, information-rich, globalised world" (ACARA, 2017, p. 1), it is pertinent to consider how our present school structures serve to enable or inhibit the ambition of a three-dimensional curriculum.

Opening conversation across the common spaces and thresholds of different education contexts, such as secondary and tertiary, can allow different levels of education to share approaches to interdisciplinary activity and these ambitions for a three-dimensional curriculum. Further to this, considering connections across levels of education is essential for the identification of overarching, systemic challenges to authentic interdisciplinary ways of knowing.

While a discussion of the pedagogic approaches that enable the successful integration of creative and other disciplinary approaches in STEM teaching and learning contexts is outside the scope of this paper, the Office of Learning and Teaching Discovery and Innovation project 'Multiple Measures' (Tregloan, Wise & Fountain, 2016) provides some insights. Focussing on the tertiary sector, this national survey of approaches to interdisciplinary assessment design considered two broad goals for interdisciplinary learning: *deepening* expertise by drawing in related skill sets and knowledge; and, *broadening* skills - include the 'soft' skills arguably favoured by future employers (Jefferson & Anderson, 2017) - and ways of knowing by engaging with dispersed disciplinary fields.

The ways in which interdisciplinary education is being delivered in the Australian tertiary context can inform how interdisciplinary teaching and learning is understood and transferred to other levels. For example: how do we move beyond the model of the 'T-shaped' learner, often associated with the tertiary sector and AQF Levels 7-10? The notion of the T-shaped skillset developed in the late 1970s through analysis of management practices and entered mainstream vocabulary and commentary in the 1990s. Interestingly, it remains especially prevalent in the classic STEAM domain of software development. By analysing Australian tertiary case studies based in the Humanities and

Creative Arts, the Multiple Measures project also identified examples of teaching approaches that enabled *both* depth and breadth: combining the self-directed, single focus, long duration of the depth-orientated project, with the scaffolded, multi-parted, often collaborative approach of breadth case studies. Rather than the familiar 'T-shaped' acquisition of skills, where depth and then breadth are developed independently and sequentially, these projects suggested the simultaneous development of depth and breadth: developing a rounded and dimensional 'X-shaped learner' (Tregloan, Wise & Fountain, 2018).

The potential to employ relational and reciprocal insights from and across the spectrum of tertiary, secondary and education contexts is worthy of further exploration, as is consideration of the different enablers and inhibitors teachers encounter across different contexts. To do so is to extend the notion of non-hierarchal discipline privileging in order to recognise insights pertaining to pedagogical content knowledge practiced across the gamut of education contexts (MacDonald, 2019). For example, the findings from the Multiple Measures project assume a level and depth of disciplinary knowledge, which may not always be present for those teachers working in early and primary years of schooling (Cunningham, Perry & Stanovich, 2004). However, they do suggest ways to integrate modes of learning associated with different knowledge domains, as well as identifying potential barriers for successful enactment of learning modes in contexts that impact tertiary education. In relation to the secondary education space, the findings reiterate the challenge for teachers working in siloed disciplines, or subject areas, aligning powerfully with Marshall's (2014) call for transformation of the constraints that disciplinary silos pose for teachers working in the secondary schooling system. Transformation of the ways in which engagement and interaction is enacted across the spectrum of education levels is necessary if we are to "inspire new models of practice in an education system sorely in need of change" (Marshall, 2014, p. 125), and deliver on the full potential envisioned in our three-dimensional Australian Curriculum.

These commentaries indicate the need to remain open to and mindful of the potential for interdisciplinary approaches to teaching and learning, and how these aspirations can manifest innovative and workforce-ready education outcomes. To better understand what STEM and STEAM education can achieve, one approach may be to pay closer attention to the ambiguous 'in-between spaces' of the disciplines contained without the eight LAs of the Australian Curriculum, and how the GCs and CCPs can be enacted as disruptors that foster interdisciplinarity education, for transdisciplinary outcomes. Also emerging from these commentaries is a need for further consideration to be given to the threshold spaces between education contexts and levels that might yield fresh insights for how we theorise and achieve relationality between disciplinary ways of knowing and interdisciplinary pedagogy.

Entwining Disciplinary Perspectives Across Three Australian States

The authorship team who developed this article work across a diverse range of disciplinary backgrounds and education contexts pertaining to STEM and STEAM education. As such, this article is an entwined narrative that draws from and across our respective STEM and Arts industry collaborations, as well as teacher education and tertiary education contexts. We also acknowledge that our elicitation of insights and subsequent meaning making emerges from our individual perspectives of disciplinary expertise in those contextual spaces, which include strengths in Science, Mathematics, Humanities and the Creative Arts.

Abbey MacDonald is an artist, teacher and researcher working in Higher Education (Arts teacher education) at the University of Tasmania. She is an arts-based researcher who works in scoping relational intersections between arts-based methodology and pedagogy (see MacDonald, Baguley & Kerby, 2017) and interdisciplinary applications in teacher professional learning contexts (see MacDonald, Hunter, Ewing & Polley, 2018). MacDonald's priority research contexts include brokering professional learning collaborations (see MacDonald & Wightman, in press), enacting interdisciplinary curriculum (see MacDonald & Polley, 2019) and cultivating broad community values in and through Arts education contexts. Further to her work in Arts teacher education and professional learning, MacDonald advocates for access to quality Arts education for all Australians through her role as vice president of Art Education Australia, which is the peak national body for visual art education in the country.

Jane Hunter works from the STEM Education Futures Research Centre at the University of Technology, Sydney in New South Wales (NSW), where she has conducted a series of STEM Category 2 funded research studies in public schools (2016-18). To date, the work has involved 14 NSW primary schools, more than 59 teachers and approximately 1500 students aged 5-12 years. The three mixed methods studies included professional learning (PL) with a pedagogical focus using the *High Possibility Classrooms* (HPC) framework (see Hunter, 2013; 2015); conducted in schools for 3 - 15 months. This research was designed to build teacher capacity and middle leader agency in STEM education, which when enacted in programming and in classrooms often became STEAM with the 'natural inclusion' of the Arts and the Social Sciences. Participants used inquiry, project-based and design challenge approaches underpinned by the *High Possibility Classrooms* (HPC) framework (see Hunter, 2017).

Kit Wise has engaged in an advisory capacity with creative arts schools on course design and interdisciplinarity around the world, including Singapore, New Zealand, Canada and Australia. His interest in K-12 STEAM education builds upon the successful Office of Learning & Teaching Innovation & Development grant *Benchmarking quality assessment tasks to facilitate interdisciplinary learning in the creative arts and humanities*. Wise collaborates with MacDonald and other colleagues across various disciplines to explore the application of those findings within tertiary contexts, potential translations and insights for school education and wider disciplinary networks, as well as the specific interdisciplinary field of STEAM education (see MacDonald & Wise, 2018; MacDonald et al., 2018).

Sharon Fraser's involvement in Science and Mathematics Education research since 2013 in Tasmania has a distinct focus on integrated STEM education. Capacity building through Professional Learning (PL) has always been the driver for her engagement in research, and in particular in PL for teachers in rural, regional and remote settings (Fraser et al., 2019) and/or those teaching out of field (Beswick, Fraser & Crowley, 2016).

Fraser's research focuses on collaborative 'STEM' education research, by bringing together a team of academics with complementary research interests and capabilities, in order to re-conceptualise the notion of 'integrated STEM'. Recent and ongoing Category 2 research funded projects continue to focus on PL, but with a renewed focus upon leadership, whole of school approaches, and a capability approach to capacity building. Leadership is an essential element in developing school culture, which embraces interdisciplinary approaches to learning and teaching in the face of an Australian Curriculum that sustains disciplinary siloes. Fraser's research to date embraces a continuum – incorporating cascading STEM education capabilities for principals, teachers, students, the community and the educational researchers – that are essential for effective evidence-based, interdisciplinary and integrated STEM education.

Methods, Mediums and Design: Architecture for Imagining Disciplinary Possibilities

In order for the authorship team to provide insight into how we discerned various disciplinary STEM and STEAM education agendas being interpreted and enacted within three Australian states, a reflective analytic process was adopted. From our different contextual positions of disciplinary expertise, the authorship team adopted a constructivist approach to facilitate vibrant discussion and the sharing of perspectives. Through articulation and involvement of individual storylines we "collaborated in the telling and retelling of stories of what has past, and in the co-creation of stories for the present and the future" (Beattie, 1995, p. 65). This methodology, of distilling and examining individual lived experiences and observations, feeds into a 'writing of stories' towards collective applications and possibilities. This in turn creates space for the transformation of living stories, and articulation of possibilities for future storylines to converge (Leggo, 2008).

The propositional question framed to facilitate initial entry points for data generation was:

- *What policy, reforms, reports, priorities and trends are driving/shaping interdisciplinary education agendas within the context of the Australian states in which we work? (NSW, Tasmania, and Victoria)?*

Using this initial question to frame our approaches, we independently revisited our individual experiences of working in higher education contexts in teacher education and the creative arts, to consider how we were encountering disciplinary acronyms, such as STEM and STEAM, and how we have observed their mobilisation within broader disciplinary agendas. From this focus, we each developed a short storied vignette, for the purpose of sharing, reflective analysis and collective meaning making. Individual storied vignettes enabled us to construct a profile of various disciplinary profiles within our respective state contexts for the purpose of sharing and meaning making. These profiles were constructed in consideration of the events we determined, from our positions of encounter and expertise, to be critical to shaping predominant mobilised ambitions; and, the degree to which these enable and/or inhibit the realisation of STEM, STEAM or other disciplinary agendas, in and for school education contexts. The authors engaged with each other throughout the research process in ways akin to that of bricoleurs (Levi-Strauss, 1962), adopting co-constructive interpretations of individual and collective strategies, in order to make sense of our lived experiences of working relationally in higher education / teacher education contexts.

After the formation of vignettes, a second stage of data generation and meaning making was employed, from which two sub-questions emerged:

i) *What are the common and/or contrasting critical events underpinning the formation and enactment of these disciplinary agendas; and*
ii) *How are these critical events impacting on approaches to STEM and STEAM education in our respective Australian state contexts?*

These two sub-questions provided a common threshold for further encounter, as well as supporting discussion regarding thematic commonalities that emerged across the vignettes (MacDonald, Hunter, Ewing & Polley, 2018). Through this entwined process of retrospection and reflection, we intersected individual and shared dialogue to develop critical storylines, from superfluous 'like' and 'other' through lines (Webster & Mertova, 2007). This multi-layered process of data generation and critical reflection identified both synergies and contrasting approaches to distinct disciplinary agendas unfolding in New South Wales, Tasmania and Victoria. The accumulation of critical storylines facilitated the authors to draw mean between critical events "to index answers which the whole set can offer to the problem" (Levi Strauss, 1966, p. 12).

Allowing the prioritisation of specific disciplinary hierarchies to be made explicit provides a means to index possibilities for the bigger picture problem (Levi Strauss, 1966). In so doing, we adapt McCarthy et al.'s (2001) proposition to interrogate and reframe how we encounter storylines that might advocate for the inclusion or exclusion of particular disciplines in education contexts. The architecture of this process aligns with what Beattie (1995) describes as a collaborative, qualitative approach where the concept of interacting storylines is used to "further explore the meanings of teaching, learning and professional interactions" (p. 66).

Vignettes of Professional Contexts: How NSW, TAS and VIC Interpret and Enact Disciplinary Agendas in Education Contexts

The following section identifies the outcomes of the methodological process the authorship team used to distil the critical storylines that capture what is happening in relation to STEM, STEAM and/or the potential for other disciplinary agendas in the three respective states. The vignettes elicit insight into individual experiences of, contributions to, and/or the implications of being subjected to the disciplinary agendas in which the authors work. Drawing on these three vignettes, further discussion focuses on an entwined meta-storyline, where the critical themes, enablers and inhibitors operating across contexts are identified, leading to more incisive consideration of their implications and possibilities.

New South Wales

Distinct from the other states New South Wales (NSW) does not have a stand-alone STEM or STEAM education strategy (Gotsis, 2017). It does however have an innovation strategy and documentation cites NSW as having satisfied the *National STEM School Education Strategy 2016-2026* (Education Council, 2015) by developing online resources, 14 action schools, minimum standards for the Higher School Certificate (HSC), strengthening teaching standards and reforming the curriculum by introducing iSTEM electives in the later stages of schooling (NSW Department of Finance, Services and Innovation, 2015). In NSW a range of other undertakings are shaping the study of what is deemed integrated STEM in primary and secondary public schools, that include its investment in *Education for a Changing World* agenda on the strategic implications that advances in technology will have for education (Loble, Creenaune & Hayes, 2017).

NSW is a jurisdiction with more than 1 million students serviced by 2400 schools. Since 2017 the effort has revolved around "the delivery of quality STEM education for all students to ensure:

- raising expectations and enhancing the quality of student learning in STEM
- fostering quality teaching and leadership in STEM
- innovative ways of delivering STEM education" (NSW Department of Education, 2018).

The language of the various STEM websites principals, schools and teachers can access are primarily concerned with quality STEM, authentic experiences, project-based learning and a focus on the final years of primary schooling onwards into secondary education. In addition to that previously mentioned, STEM education provision is supported by two dedicated STEM advisors, a team of experienced curriculum advisors in Science, Technology and Mathematics, the STEM share program of kits of 'hands on' loaned resources ($23 million program funded by the NSW State Government), mentoring programs, online templates, teacher surveys to understand what schools are doing in STEM, participation in the Principal as STEM Leaders (PASL) research study, STEM school and industry partnerships and bespoke professional learning resources that all teachers can access alongside national assets from the CSIRO and so on. Within the activities/resources are six principles of STEM education that give voice to the pedagogical drivers (STEM NSW Department of Education, 2017):

1. To activate and build students' prior knowledge.
2. To provide opportunities for students to organise information and understand influences and how they learn and apply new knowledge.
3. To generate students' motivation that determines, direct and sustains what they learn in STEM.

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4. To develop fluency and automaticity to ensure students must acquire component skills, practise integrating them and know when to apply what they have learned in STEM
5. To foster goal-directed practice combined with effective feedback to enhance quality of learning using design challenges and feedback from peers, teachers and self-evaluations of their solutions.
6. To become self-directed learners to enable monitoring and adjustment of their approaches to learning.

Furthermore, the NSW Education Standards Authority (NESA) has developed a number of cross curriculum sample units in STEM; advice on programming is provided alongside outcomes that target the Mathematics, Science and Technology syllabus documents from K-12. The place of an interdisciplinary focus for STEM in policy documentation revolves around pedagogy, specifically inquiry, collaboration and design thinking. STEAM education on the other hand receives scant citation in key reports and in one brief mention in website documentation it refers to STEM education in South Korea and that without the Arts, creativity and engagement in the STEM disciplines would suffer (Gotsis, 2017). Outside stated directives some individual schools are declaring a focus on STEAM through maker spaces and 'future-focused learning'. The main conversation in NSW public schools revolves around the need for STEM education to bolster declining education outcomes since 1995 and in particular, in two disciplines, Mathematics and Science.

Tasmania

Despite being Australia's smallest state, Tasmania is experiencing rapid growth in its population and has the fourth best performing economy in the country (CommSec, 2018). It continues to experience significant socio-economic challenges, with the lowest level of educational attainment in Australia (Allen et al., 2017). The Tasmanian education system is unusual in that in the Government sector in particular, the education system traditionally incorporates an extra transition point for students continuing onto year 12, requiring students to leave their district school to attend a College located in one of the major cities (Hobart, Launceston, Burnie or Devonport). Further to this, Tasmania is reported to experience "persistent underperformance in the transition to Year 10 and subsequent retention rates to Year 12" (Stratford et al., 2016, p. 4). It is estimated that Tasmania is 10,000 tertiary enrolments behind the next lowest performing state (Department of Premier and Cabinet, 2018), with significant challenges in encouraging students to complete Years 11 and 12

At the same time, Tasmania is host to arguably one of the most vibrant interdisciplinary creative community in Australia (Grimmer, 2017; Lehman & Reiser, 2014), as exemplified in a thriving local, interstate and international art exhibition calendar, and annual festivals such as the Museum of Old and New Art (MONA)'s DARK MOFO winter festival, the MONA FOMA summer festival and Junction Arts Festival (JAF). A significant feature of the Tasmanian context is the 'STEAM' interests of many of these festivals and institutions; most notably, MONA, which has sustained record of curating world-acclaimed art/science exhibitions.

Like all Australian states, STEM education in Tasmania draws its focus from the National STEM Education Strategy (2015). Both government and non-government within the state have developed their own responses to this strategy and are currently at different stages of implementation. The Tasmanian Department of Education (2015) commits to an interdisciplinary approach to STEM education in which:

> STEM approaches highlight connections between the learning areas of Science, Mathematics and Technologies (which can include engineering) and the broad capabilities and dispositions learners will need in a rapidly changing world. (para. 2)

Leadership is an essential element in developing a school culture, which embraces interdisciplinary approaches to learning and teaching in the face of an Australian curriculum that presents disciplines as 'siloes'. Our current research embraces a capability continuum– incorporating cascading STEM education capabilities for principals, teachers, students, the community and the educational researchers – that are essential for effective evidence-based, interdisciplinary and integrated STEM education.

For STEM education in Tasmania, teachers are encouraged to engage learners with concepts from the disciplines of science, mathematics, technology and engineering (design and technology) through real world and authentic projects and challenges. In support of this goal, a STEM Framework (2017) has been developed, encompassing Tasmanian Government school learners from the Early Years to Year 12. Its goals, objectives and five principles align with the National STEM School Education Strategy (Education Council, 2015). Each of these principles has been unpacked for teachers and the community in more detail on the Department's website, and units of work shared for use by teachers throughout the state from both the Department schools and the other Independent and/or faith-based schools.

The approach draws upon the fact that almost one third of Tasmania's land area (~68,000 square kilometres) is consigned to agriculture. In recognition of the importance of this (STEM-rich) sector to the state, the government has supported the creation of new subjects for years 11 and 12 in Tasmanian Agricultural Education. These subjects are part of the Tasmanian Agricultural Education Framework (2016), which underpins the curriculum, career connections and stakeholder partnerships as enablers of learning from Preparation to Year 12. It was collaboratively developed by the Department of Primary Industries, Parks, Water and the Environment (DPIPWE), the Department of Education and the Hagley Farm School: Centre for Agricultural Education. In order to realise the potential of the framework, the Tasmanian Government has invested in professional learning, and has promised 250 additional teachers and 80 teacher assistants in its public schools, with $4.9 million invested over a period of 4 years to provide 10 new teaching staff to support Farm Schools (e.g., Hagley Farm School) as well as further money to support the operational costs of running the farms. This acknowledgement of the importance of agriculture for the prosperity of the state provides a wonderful springboard for STEM-rich activities that have real world relevance to students.

Further to STEM, there is a recognition of and interest in STEAM and wider interdisciplinary education initiatives. In 2018, the University of Tasmania partnered with the Department of Education (DoE) to deliver a STEAM professional learning event, STEAM Horizons. This collaborative delivered its initial pilot implementation activity in 2018 as a multi-site, live streamed professional learning event (The STEAM Horizons Symposium) for a group of 70 teachers across Tasmania. Live streaming between school venues in the north, south, and north west generated a virtual community of practice. The STEAM Horizons professional learning collaborative team delivered an event which early evaluation suggests successfully empowered teachers and students, through showcasing the ways in which teachers around the state are enacting STEAM teaching and learning in their respective school contexts. Such was the success of and support for the 2018 symposium; a 2019 iteration is currently being developed for delivery later in the year.

The STEAM Horizons 2018 professional learning initiative, along with its associated research evaluations and publications (MacDonald et al., 2018; MacDonald & Polley, 2019), have enabled University of Tasmania and the DoE to start working more closely, fostering rapport between Arts education pre-service education, arts education professional learning associations, and the DoE Curriculum Leader for The Arts. In collaborating with key education stakeholders to develop a working definition (MacDonald et al., 2018) for how we were observing and experiencing STEAM education to unfold in Tasmania, we created a holding space for possibility, reflection and transformation. The STEAM Horizons professional learning collaborative situates itself in reference to The Education Workforce Roundtable Declaration (2018) priorities; which call for the University of Tasmania to work in partnership with the Tasmanian Government and wider community to bring about educational transformation. This agenda is strengthened through the creation of links between the University, schools, colleges and TasTAFE; to build "educational aspiration and participation and improved educational outcomes in all regions of Tasmania" (Department of Education, 2018, p. 2)

Victoria

While outcomes from the current initiatives being implemented in K-12 STEAM education are yet to flow through to students entering into university education, the tertiary sector has been engaged with similar interdisciplinarity enactment concerns for some time. In Victoria, the 'Melbourne Model' was launched at the University of Melbourne in 2008 (Devlin, 2008). In the Australian context this was a ground breaking, breadth-driven undergraduate curriculum that promoted multidisciplinary learning experiences. Several leading universities subsequently followed suit with either very similar iterations of the 'Melbourne Model' (University of Western Australia), or, enterprise-scale curriculum renewal to embed breadth offerings (including Australian National University, Monash University).

While the Melbourne Model does not identify or prioritise specifically STEAM or other expanded-STEM discipline groupings, it aims to produce forward-thinking graduates who are skilled and resilient:

> "A Melbourne degree provides graduates with in-depth knowledge of their specialist disciplines and skills in examining issues with multiple disciplinary perspectives. Melbourne graduates are critical, creative thinkers with strong reasoning skills. They can apply knowledge, information and research skills to complex problems in a range of contexts and are effective oral and written communicators. The Melbourne educational experience prepares graduates to be entrepreneurial and innovative thought-leaders. Melbourne graduates bring research and inquiry skills to challenges in their workplaces and communities. They are adept lifelong learners who generate bold and novel ideas by critically evaluating alternative possibilities and viewpoints" (University of Melbourne, 2019, para. 3-4)

This ambition aligns with research on the importance for graduates of so-called 'soft' skills, including creativity, critical reflection, communication and collaboration (Jefferson & Anderson, 2017). Through the breadth emphasis of degree structures such as the Melbourne Model (typically found at Australian Qualifications Framework Level 7), students are encouraged to engage with a wide range of epistemologies, gaining experience across Biglan's (1973) 'hard and soft', 'applied and pure' discipline paradigms, later described by Kolb's (1981) learning style index of 'abstract-concrete' and 'active-reflective' orientations of academic fields. Familiarity with different approaches to knowledge construction, learning and problem solving are understood to be advantageous, developing the flexibility needed for graduates entering future industries.

The Melbourne model is an inversion of the common 'T-shaped' learning pathway, with broad (horizontal) undergraduate study complimented by deeper (vertical) learning within professional fields. Most professionally accredited courses, such as Architecture, require the Masters level qualifications to allow entry into the industry. As such, it shares the 'inverted T' pattern (Tregloan et al., 2016; 2018) of interdisciplinary education observed in the Australian K-12 curriculum, where there are generally greater opportunities for broader interdisciplinary learning (such as STEAM) in earlier schooling levels with a more focused, prescribed curriculum in senior year levels.

However, an important distinction is the "multiple disciplinary perspectives" associated with, in this example, the Melbourne Graduate. The integration of disciplinary domains and learning styles in, for example, play-based primary school STEAM pedagogy is a key feature of *interdisciplinary* learning (Davies & Devlin, 2010), achieving the 'soft' skills of creativity, critical reflection, communication and collaboration identified by Kivunja (2015). However, this integration is by definition, absent in the multidisciplinary approach made explicit in the Melbourne Model; calling into question whether those soft, transferable skills are achieved.

STEM and STEAM and the Spaces Between: Collective Implications of the Enablers and Inhibitors for Disciplinary Agendas Across Three Australian States

The storied accounts presented in the following discussion emerged through a process of ongoing peer reflection, review and writing. The authorship team identified converging points for individual and collective stories (Clandinin, Connelly & Chan, 2002) in diverse education contexts; storying in and through forms created as sites of sophisticated knowledge, in sites of higher knowledge (Phillips & Bunda, 2018). This discussion unfolds from the three overarching questions previously discussed, that the authorship team collectively distilled to enable data generation, sharing and meaning making processes. These questions provided a lens through which the authors were able to determine the critical through lines, used to inform the assemblage of a 'bigger picture' multi sector collective vignette for our three states (NSW, TAS, VIC). The following discussion provides insight into how the authors collaboratively render the situational, temporal, and social aspects of deficit and/or enabling storylines that have historically marginalised some disciplines at the expense of elevating others.

The various conceptualisations of disciplinary agendas articulated and examined in this article embrace approaches and philosophies that deeply impact teachers' own pedagogical acts of transformative learning (Tregloan et al., 2018). The approach resonates with Hatcher's compelling argument about teaching and learning needing to expand beyond simplistic notions of knowledge transfer and acquisition to embrace more enriching conceptions of relational and interdisciplinary education (Hatcher, 2011). Without such foundations, the story of innovative interdisciplinarity might only be a novelty as perceived by localised opinions of the virtue (or not) of bringing STEM and the gamut of other disciplines together (Stokes, 2018).

Emerging across the vignettes is the recognition that the teaching of integrated STEM or STEAM requires a change in teacher pedagogies to encompass real world problem solving or design-based approaches (Fraser et al., 2019). It is inherently risky for an individual teacher to move into a liminal space (such as interdisciplinary STEM), which by definition is one that is yet to be supported by rich, relevant and readily accessible resources. However, this risk-laden space offers immense potential for a truly relational and non-hierarchal education experience; one that is curious, provocative, disruptive and complex and is therefore worthy of our attentive perseverance. This complexity, which has the potential to serve as either an enabler or inhibitor, embraces the aspiration of transformative teaching and learning experiences. The challenge of leveraging the optimum degree of risk to generate innovation is a delicate balancing act. Fostering uncertainty whilst providing just enough definition, support and permission for teachers to feel adequately empowered, captures the precarity of the threshold upon which the vision for successful interdisciplinary education is located. Common agendas and priorities impacting upon STEM and STEAM education emerging across the three states compel teachers to dissolve and transcend disciplinary boundaries through enactment of emergent interdisciplinary pedagogies that generate interdisciplinary learning outcomes. What happens in the spaces between STEM and STEAM disciplinary intersections emerges as an integral space, within which risk, mess and disruption foster key 21st century skills in teaching and learning, industry and life. Several significant challenges exist for teachers seeking to enact the necessary pedagogical transformations required to achieve meaningful and authentic interdisciplinary STEM and STEAM education outcomes in Australia. The deeply entrenched disciplinary privileging and siloing that characterises the current schooling system - particularly in the secondary context - is highly problematic (MacDonald, 2019). Before teachers can collectively engage in the authentic interdisciplinary collaboration necessary to dissolve disciplinary barriers, the organisational structures within and from which the majority of Australian schools operate are already in conflict with this aspiration. Here, attention to the 'spaces between' might help elicit what is missing, by identifying what is essential to achieve 'stated' education aspirations. For teachers to be able to mobilise the three-dimensions of the Australian Curriculum in ways that allow for an authentic entwinement of disciplinary skills, capabilities and ways of knowing, they need to be empowered to improvise and challenge their own practices, try new working methods, and break routines without fear of criticism and punishment (Harris & de Bruin, 2017). Across the three states, there is insufficient evidence of planned or equivalent structural or systemic change that will better support teachers to 'meet' the postulated pedagogical transformations necessary for STEM and STEAM education to thrive.

How to assess students in these spaces is largely absent within all of the agendas. This key observation emerges as a major inhibitor; an 'elephant in the classroom', in terms of impacting the lived activation and mobilisation of STEM and STEAM. For example: there are no stand-alone places to report interdisciplinary learning within half-yearly and annual documentation in New South Wales, Tasmanian and Victorian schools. Teachers are not able to specifically assess and report STEM or STEAM learning outcomes. The structure of most school assessment systems has not yet adopted the revisions necessary to meet the innovative pedagogical transformations being promoted in STEM education strategies. Teacher comments or a lone assessment mark in school reports for example, are common. Finding ways to formally assess, capture and value these liminal spaces must be prioritised.

Future Directions Pertaining to 'Disciplinarity' Across Three Australian States: A Wish List

Emerging from this discussion spanning three Australian states is the need for a collective commitment to action. The emphasis on disciplinary agendas in political and policy frameworks for education might well be paused, to better reflect on the X-shaped teachers required to embolden X-shaped learners, through clearly articulated, inclusive and enabling expectations. This notion of the 'X' shaped individual – where 'X' can also function as being resistant to, or yet to be defined – establishes a liminal space in which the possibilities for future interdisciplinary directions can be considered. In closing, this article summarises the gauntlet laid down by the collective analysis the disciplinary agendas and priorities of three states.

In NSW questions remain about how the STEM push will continue to gain momentum if sustained funding for teacher professional learning is not highlighted in state budgets. The very nature of STEM and STEAM as resource intensive fields, where access to materials, disciplinary expertise from outsiders, alongside continued opportunities to build capacity of teachers must support the profession's enthusiasm to date. End of schooling credentialing structures like ATAR (Australian Tertiary Admissions Ranking) and the NSWHSC (Higher School Certificate) act as systemic hurdles, and while STEM and STEAM projects, programs and inquiry in the K-10 years of schooling are providing innovative learning opportunities for young people, their ubiquitous experiences are constrained or at significant risk of being unravelled in the final siloed years of secondary education.

Furthermore, the University of Technology Sydney (UTS) has a bespoke Faculty of Transdisciplinary Innovation, where programs are designed to meet the needs of industry for novel approaches to complex applied problems. This development is applauded and through its example of success, places more pressure on school systems to align and pay attention to the kinds of learners that will more seamlessly move into such courses with strong interdisciplinary foundations.

Tasmania is characterised by its socio-economic and cultural complexity that concurrently derives from and impacts on education outcomes for students and communities. In 2016, the

Australian Bureau of Statistics reported that only 51% of the Tasmanian population held a post-school qualification, while a more recent report from the Australian Council of Social Service (Davidson, Saunders, Bradbury & Wong, 2018) highlighted that more than 120,000 people (23.6%) in the state are living in poverty, including 15.8% of children aged under 15 years. Education is acknowledged as key to addressing poverty in Tasmania. The STEM strategies developed across the state are underpinned by the aspiration to transform the cultures that continue to inhibit educational attainment, aspiration and wellbeing. The translation of a STEM vision into real world applied learning opportunities is apparent in pockets, however is uneven and contingent upon State government's preparedness to continue investing in the STEM-centric professional learning essential to support schools and teachers. In addition, a lack of attention has been given to the implications of siloed structures of secondary schooling to ascertain how they enable and/or inhibit interdisciplinary education agendas. Enabling collaboration across disciplines underpins the capacity to re-conceptualise education agendas in Tasmania.

In Victoria, there are ongoing concerns regarding perceived misalignment between the interdisciplinary learning outcomes desired by the tertiary sector from STEAM and other discipline combinations, and the pedagogies employed. Successes have much in common with early childhood and primary schooling models; however, in parallel to the secondary education sector narratives in New South Wales and Tasmania, the primary challenge is the professional support, structure and leadership required to allow teachers time, space and resources to speculate, experiment and innovate. Without this capacity, the ability to deliver work-ready graduates for future industries is challenging.

Universities need to prioritise the promotion of genuine inter and transdisciplinary studies within Faculties of Education; studies that are concurrently underpinned by and informing the future shaping of authentic inter and transdisciplinary teaching and learning experiences. When desired outcomes for learners embody, activate and enact the full spectrum of disciplinary mindsets, be these STEM, STEAM or other disciplinary assemblages that mobilise the breadth and depth of disciplinary fields of knowledge and ways of knowing, then it may be possible to realise the full potential of the Australian Curriculum. Alignment across all levels of education is possible through collaboration where leadership, resource sharing and stakeholder engagement prioritises inclusive disciplinary perspectives and language.

Re-inscribing tensions between disciplines by fixating on arguments over the assemblage of particular disciplinary hierarchies are a disservice to our collective realisation of interdisciplinary aspirations. In saying this, disciplinary acronyms are without doubt playing an important step in enabling articulation of our journey towards fostering interdisciplinary visions for transformative education outcomes. In order to avoid getting caught up in the battles of disciplinary hierarchy, education across all levels has an important role to play in how we work with teachers, students, researchers, industry and communities to be more collective and collaborative with these tensions. The spaces between disciplines, and levels of education, can create spaces in which we can step outside our respective contexts to look at how disciplinary hegemony, privilege and marginalisation are shaping our education system. Such contemplation is necessary if we are to get a genuine sense of how our enactment of disciplinary agendas is 'making way' or 'getting in the way' of the collective work we need to do together.

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BOOK REVIEW

STEM Education: An Emerging Field of Inquiry

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The collection of articles in the book provides insight into what constitutes STEM education and practices that could be used to further STEM teaching and learning in K-12 programming and teacher education with a focus on the Australian context. The articles are arranged in an order that flows well from the larger picture and definition of STEM education and the reasoning behind the call for more focus on STEM in schools and pre-service teacher education, to specific examples of how to incorporate STEM into practice, ending with a consideration of the future possibilities. Each of the chapters is well written and provides theoretical and research bases for their arguments. Having read each of the chapters, I have a clearer sense of what constitutes STEM education and how I might go about incorporating the philosophy of STEM into practice at the K-12, pre-service teacher, and in-service teacher level.

The introduction by Barkatsas, Carr, and Cooper is clearly written and lays a compelling foundation for the need to spend more time and energy researching effective STEM education practices. The concern of declining enrolment in STEM fields and the growing need of innovators in the global marketplace is one that Barkatsas, Carr, and Cooper highlight and is revisited in several of the chapters throughout the volume. In addition, they note that “Educators at all levels are grappling with the complexities and issues that are emerging in what is a relatively new, and some might argue, ill-defined field” (p. 2). As such, this book begins with a chapter presenting a definition of STEM that highlights some of the complexities while offering a reconceptualization of the organization of teaching and schools to foster the development of both disciplinary knowledge and skills that transcend specific disciplines.

Fraser, Earle, and Fitzallen present a comprehensive historical overview of the development of STEM as a focus in both education and the evolving demands of the workforce. One compelling statement from the authors regarding why science, technology, engineering, and mathematics are placed together and focused upon is “while we need science and mathematics to understand the world around us, it is through engineering and technology that we interact with and mould it” (p. 11). This articulation by Fraser, Earle, and Fitzallen provides a way of thinking about how one might consider teaching in a STEM context. The authors also stated that “At the heart of the term STEM, therefore, is the supposition that there an inherent connectivity of the four disciplines that is well understood and that should lead to meaningful integrated STEM learning” (p. 11). The key to a rich STEM learning environment is leveraging the connectivity between the disciplines while not sacrificing what makes each discipline unique. However, the current structures in education do not allow for easy opportunities for teachers to connect the disciplines in a rich fashion.

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In order to achieve a connected learning experience for students, Fraser, Earle, and Fitzallen point to the role of teachers and disrupting current beliefs and practices with respect to the way science, technology, engineering, and mathematics exist within a school structure and the way that they are taught. In looking to future goals of STEM education, they state that the interdisciplinary nature of STEM "is more than achieving an increased understanding of its individual disciplines, rather it challenges teacher beliefs about their discipline or disciplines, how they interact, and are taught and learned and therefore, the pedagogies and practices that they adopt" (p. 23). The message that teachers are key to the successful implementation of integrated learning experiences for students is echoed in several chapters in this volume. As Fraser, Earle, and Fitzallen note, teacher professional development and initial teacher education need to support teachers in making pedagogical decisions that reflect the philosophy of STEM education. This introductory chapter sets a solid foundation for the rest of the chapters that then point to specific ways in which this goal can be achieved.

Chapter 2 by van Driel, Vossen, Henze and de Vries is a nice follow up to the first chapters as it presents a project in which the principles of STEM education that are highlighted in the first chapter can be integrated into a research and design course. This course is not discipline specific but integrates the disciplines. The goal is to highlight the work of professionals in the STEM disciplines, where "professionals in different disciplinary backgrounds work together in teams" to find an optimal solution to a problem where "there is never one correct answer" (p. 34). The focus on design principles and the opportunity for students to engage in current research and design challenges are fundamental to the success of such a program. Though this chapter does not report on research relating to the implementation of a research and design course, the description of how it was enacted in a specific context sends an encouraging and hopeful message that integrated STEM educational experiences are possible.

One element of prompting a focus on STEM education that several chapters refer to is the development of a 'pipeline' of training for students to enter STEM fields, which is specifically noted in Chapters 1, 2, 3, 4, 5, and 10. The notion that the purpose of STEM education is to funnel students into careers that use disciplines brings forth an image of students sliding down a tunnel and dropping into boxes from which they cannot escape. This was probably not the intent of the use of that description, however, regardless of the changes that are made to incorporate STEM principles into education systems, there is not enough known about what that impact might later have on careers in the future. As was noted in Chapter 3 by Jordan, a focus on STEM education in schools has decreased the performance and enrollment of students in mathematics and science specifically. Perhaps a focus on an integrated STEM approach in schools is turning students away from siloed learning in post-secondary. McLaughlin and Kennedy, in Chapter 12, commented that "learning and teaching in the science, technology, mathematics, and engineering disciplines often remains narrowly focused and content entrenched, especially in tertiary education" (p. 210). If students have an integrated set of learning experiences in school but then are faced with strict disciplinary knowledge in tertiary education, maybe this is then turning students away. Changes at all levels of education are key to sustaining change.

The positioning of STEM education in policy documents by Jordan in Chapter 3 through discourse analysis shows six themes that highlight the importance that these documents are placing on STEM education in Australia. The six themes are: STEM as a national enterprise; STEM as sustaining economic growth; STEM as maintaining prosperity; STEM as not being left behind; and STEM as declining. These themes show that STEM education is positioned in policy documents as "the means for Australia to maintain its economic advantage and for Australians to maintain their prosperous standard of living" (p. 58). Jordon comments that carefully reading policy is important "to understand both the vision being proposed and the roadmap presented to us to follow" (p. 46). She also cautions though that we "need to be mindful that official dominant discourses need to be tempered with the messy realities of use in schools" (p. 47). The vision being proposed of a pipeline of workers into STEM fields in order to maintain a level of prosperity is met with the realities of children, teachers, and school systems, which cause changes to the proposed roadmap.

While the first three chapters focus on STEM education in a holistic way, the next five chapters attend to specific content areas within STEM. Cooper and Thong's chapter on virtual reality is the first of the five. They offer a historical perspective on the evolution of immersive virtual realities and provide examples of how this technology could be used to support STEM education. Cooper and Thong discuss four elements of a "*VR Education Model* (VEM)" (p. 66, emphasis in original) that are important when considering the use of virtual reality in education. They are: "*experiencing, engagement, equitability* and *everywhere*" (p. 66, emphasis in original). Each of these elements are described and specific examples of how each of them could contribute to STEM education are included. The authors support the use of immersive virtual reality in STEM education in stating, "Preparing students to effectively navigate, contribute to and participate in virtual environments appears to be an important future set of STEM-related skills and knowledge" (p. 71). Though this chapter does not describe a specific research project exploring the VR Education model, the theoretical foundation is well laid out and the examples provided give the reader a sense of how one could leverage this technology in one's practice.

Chapters 5, 7, and 8 continue with a specific content area with each chapter describing research specific to mathematics. Chapter 5 by Siemon, Banks, and Prasad focuses on multiplicative thinking development and trajectories of student learning. While the focus is on mathematics specifically, Siemon, Banks, and Prasad lay a solid foundation as to the importance of mathematical thinking to each of the other STEM disciplines and why mathematics cannot be attended to when the need arises as students solve complex problems. They state that "If the mathematics is only considered 'in passing' as a 'means to an end', it is highly likely that the teaching focus will be procedural rather than conceptual and isolated and context-specific rather than connected and generalised" (p. 77). While the authors advocate for mathematics to be taught separately, they also recognize the importance of balance between discipline specific knowledge and "the opportunity to apply this knowledge in rich, integrated settings" (p. 79). Siemon, Banks, and Prasad report that targeted, assessment driven teaching can improve student performance on multiplicative thinking tasks through describing case studies of how the targeted teaching was implemented within two schools. Though the authors make an excellent case at the beginning of the chapter for the importance of mathematics learning in STEM, they do not come back to suggest how the targeted teaching would also support student performance in other STEM disciplines.

Prodromou and Laviscza present inquiry based learning in statistics and supporting teachers to use inquiry based practices in Chapter 7. The field of statistics is presented by the authors as "vital skills for not only prospective data users, but also for all citizens" (p. 118). As such, being able to make meaning from statistical data from STEM disciplines is an important aspect to consider in any STEM program. Prodromou and Laviscza report on the setting up of classroom norms that support inquiry based learning in statistics through engaging students in rich problems and the statistical inquiry cycle. Of the three chapters specifically on mathematics, this chapter presented ideas that were the most connected to the understanding of STEM that was presented in the first chapter.

While Chapters 5 and 7 focus on the teaching of mathematics, Chapter 8 highlights cultural values and the impact those values have on what students' value in mathematical learning. Jiang, Seah, Barkatsas, Ieong, and Cheong argue that values are often neglected in research but are needed to "sensitise researchers, academics and other societal milieu on the impact research has on society, our planet and the survival of our species" (p. 133). The authors describe valuing as the "process of attaching different levels of importance to different facets of mathematics pedagogy as they experience it" (p. 139). Jiang et al.'s exploration of Macau's students' responses to the international 'What I Find Important (WIFI)' survey highlights that Macau students value "*achievement; relevance; practice; technology; communication and development*" (p. 132, emphasis in original) in that order of importance. Similarly, to Chapter 5, the authors comment on the relevance of the study to STEM education at the beginning of the chapter, there is little follow-through throughout the chapter. While the information presented in the chapter is interesting and well written, the connection to STEM education is a bit lacking.

Chapter 6 aims to illustrate how adding the Arts to STEM to get STEAM specifically with pre-school aged children in a Reggio Emilia (RE) inspired program. Gilbert and Borgerding argue that in primary education and in an RE program, an integrated approach to learning is the dominant philosophy. They stated, "teachers in these contexts have a predisposition for integrated thinking and a willingness to trust in the thinking ability of young children" (p. 103). Gilbert and Borgerding describe the contribution that including the arts as a focus in STEM to create STEAM is "to best articulate the centrality of the arts as a means for children to express and engage with their thoughts regarding content in developmentally appropriate ways" (p. 104). They then present two ways in which the tenets of STEAM were integrated into exploring the concept of air as well as specific pedagogical insights in working with young children. Though Gilbert and Borgerding frame the arts as an important additional element to STEM, their description of STEAM does not clearly identify how their vision of STEAM is significantly different than what is being described by other authors as STEM. Expression of ideas, design, and communication are significant elements of STEM education, which includes "using the Arts, as they designed solutions and tasks concerning the phenomena" (p. 115), which the authors argue is central to including the arts in the acronym. Additionally, the context for this project was a very specific and niche area of education and the integration of STEAM was presented as seamless. What would be helpful to have included in this volume is a description of a project at the secondary level where the disciplines are more siloed and fit less seamless into the STEM education philosophy. However, illustrating that STEAM learning can occur at the primary level is an important contribution.

Chapters 9, 10, and 11 each present ways in which pre-service teacher education can support beginning teachers with the integration of a STEM education philosophy while Chapter 12 articulates ways in which instructors at the tertiary level can be supported to do the same in their courses and programs. In Chapter 9, Nielson, Georgiou, Howard, and Forrester describe the pedagogical approaches that the teacher educators in the primary pre-service teacher educator program at the University of Wollongong in New South Wales utilize to support STEM education. They framed their work by articulating their vision of STEM education: "We broadly conceive STEM as an integrative view of learning where the individual disciplines provide context for explorations across fields" (p. 156). This articulation of their conception of STEM education is consistent with the beginning chapters in this volume. Nielson, Georgiou, Howard, and Forrester continue with examples of how the pre-service teacher education program is structured and approached in science, mathematics, and technology. They also describe how their program supports pre-service teachers in managing the "on-going curriculum change" (p. 164) so that students "have a broad view of the nature of knowledge" and are able to "respond to the constantly changing environment in which they will work" (p. 165). The authors offer concrete ways in which these goals could be achieved and are being achieved at their university.

Cooper and Carr's chapter continues the conversation on pre-service teacher education but focuses on, "How teachers conceptualise, interpret, and subsequently enact STEM education" (p. 170). They explore the psychosocial factors of attitudes, norms, and self-efficacy of pre-service teachers enrolled in an elective STEM education course through analyzing student responses to the question, "*What is STEM education? How do you define it?*" (p. 173, emphasis in original) and student responses to being asked to "'visualise' their confidence to teach STEM" (p. 173). Cooper and Carr noted that pre-service teachers conceptualize STEM as an integrated approach to teaching that emphasizes developing problem-solving skills. Pre-service teachers also stated that they have a positive view of STEM education but low levels of self-efficacy to teach specifically engineering and technology. In light of those conceptions, Cooper and Carr offer considerations for pre-service teacher education programs to integrate into their STEM programs. The offerings by the authors are consistent with the framing of the beginning chapters around the discourse regarding STEM education in policy documents and include encouraging pre-service teachers to read and think about policy documents critically.

Chapter 11 focuses on the development of pre-service teacher STEM identity through engaging in a mentorship program for schoolgirls that was designed "to enhance girls' self-confidence and self-identify in STEM" (p. 194). Berry, McLaughlin, and Cooper argue that "STEM identity can develop progressively through working with expert mentors in authentic contexts" (p. 193). As such, the mentorship program they describe groups schoolgirls, pre-service teachers, teacher educators, and STEM technicians. The mentoring program itself provides a unique way to engage different groups in building STEM capacity in both the schoolgirls and the pre-service teachers. The results of the study suggest that a mentoring model can support the evolution of a pre-service teacher's STEM identity in a positive way.

McLaughlin and Kennedy follow with a description of a project, called the STEM Ecosystem project, at the tertiary level to develop the capacities of academic staff in developing cross-disciplinary STEM opportunities and pedagogies. The authors note that "efforts by STEM academics to undertake cross-disciplinary industry-based projects are rare and often not sustained" (p. 210). The intent of the Ecosystem project was to "create an ecosystem of interdependent networks and collaborative leadership frameworks" (p. 212) that would be able to be sustained beyond the end of the project. Two case studies were presented that illustrated how the two specific elements of the STEM Ecosystem project were successfully enacted: the development of a supportive host environment and the "nurturing and sustainability" (p. 215) of STEM academics as leaders. McLaughlin and Kennedy found that academic "staff were empowered by their involvement in the Ecosystem and the industry mentoring opportunities" (p. 218) and that this empowerment motivated change in themselves and others. The importance of enacting change at all levels of education is highlighted in this chapter that describes an effective way to inspire academic staff to embrace STEM education at the tertiary level.

Though the collection of chapters present success stories in STEM education, many challenges enacting a STEM curriculum or philosophy are also noted throughout this volume. Challenges as noted by the authors of different chapters fall under three main categories: systematic or structural; knowledge; and resources. Systematic challenges refer to the structure of school where content is taught and assessed in discrete disciplines. Fraser, Earle, and Fitzallen comment that "The extent to which the structure of schools and schooling act as impediments to authentic and engaging STEM education…is unknown" (p. 20). This also relates to the structure of pre-service teacher education where, in many instances, pre-service teacher programs are focused on a specific discipline rather than STEM as an integrated discipline. Other systematic issues were the prevalence of large scale testing also focusing on discipline specific knowledge rather than integrated or general skills.

Knowledge challenges relate to teacher knowledge (in-service and pre-service), public knowledge, and the sharing of knowledge. Cooper and Thong point to the need for in-service teacher professional development in order for teachers to be able to feel comfortable integrating virtual and mixes reality systems into their teaching. Additionally, three of the chapters focus specifically on pre-service teacher programs (Chapters 9, 10, 11) and the role they play in developing teachers that are confident to teach STEM. Public knowledge and the sharing of knowledge are the discourse that surrounds STEM education and the availability of knowledge that can be and is shared between groups to leverage research and projects that have been conducted. Jordan in her discourse analysis of policy documents clearly illustrates a message that is “future oriented” (p. 58), “determinist” with a “fear of falling behind” and a “sense of urgency” (p. 58). These are accompanied by a “simplistic” view where complexities are “downplayed or ignored” (p. 59). A clear sense is given that if we just did A, B would most certainly follow.

Resources is the third category of challenges that are most prevalently noted by authors. These connect to financial resources to both purchase equipment that would support engaging students in worthwhile tasks and to support teacher professional learning. Additionally, resources for teachers to access that include people that are currently engaged working in STEM related fields and tasks themselves. As noted in Chapter 2 by van Driel, Vossen, Henze, and de Vries, “Many teachers have never worked outside of a school. Connecting with local STEM industries will help them to understand the realities of STEM professionals and broaden and inspire their view of STEM education” (p. 40). Though each of these challenges can be considered separately, they are connected, much like the STEM disciplines. Systematic challenges are perpetuated by a lack of knowledge or a lack of resources, and a knowledge regarding STEM fields, pedagogy, and the importance of STEM.

With respect to the specific disciplines that this volume attends to seven of the 13 chapters specifically connect to STEM as an integrated approach to education while the remaining six chapters address specific disciplines within STEM. As noted earlier, three chapters in this volume are specifically connected to mathematics. There is one chapter specifically on technology (Chapter 4), one chapter advocating for the arts to be integrated (Chapter 6). Science is peripherally addressed in Chapter 9 along with mathematics and technology. Interestingly, the collection decidedly lacks a focus on engineering. Nielson et al. comment that “we need to do more to deliberately incorporate engineering” (p. 164). This is followed by Cooper and Carr in Chapter 10 who note that “an overwhelming majority of PSTs reported not feeling confident to teach engineering related concepts” (p. 183). Even though authors in this volume note the need for support integrating engineering concepts and practices into STEM education, unfortunately this volume provides little to add to the understanding of how engineering concepts can be specifically integrated.

The final chapter, or epilogue, by Hobbs provides a glimpse into future possibilities of STEM education and provides an excellent overview of how each education partner can contribute to forwarding a focus on STEM. Hobbs also provides a vision for STEM education that includes five principles that initial teacher preparation, early childhood education, school education, and tertiary education can work together on. The five principles are: normalize STEM as an essential component of education; the normalization must be deliberate, explicit, and practiced; there is no one “way to do, learn or represent STEM” (p. 227); collaboration between and within disciplines and education partners is prevalent; and one’s efforts to incorporate STEM principles are to be documented and shared. These five principles provide an outline for ways in which interested stakeholders can work together to improve STEM education at all levels.

Overall this volume is rich in ideas that inspire the reader to rethink not only practices in STEM education, but all education. Despite the challenges that are noted throughout the chapters, the collection provides a sense of hope and excitement regarding the potential that a focus on an integrated STEM education could provide learners at all levels. Considering integrative experiences for students that highlight connections between and among disciplines serves to broaden learning beyond disciplinary knowledge but also honoring that knowledge. STEM education is an opening and widening of possibilities not a funneling or narrowing. This volume addresses four levels of education: primary, secondary, tertiary, and teacher education (pre-service and in-service) as well as incorporates research completed in four different countries: Australia, Macau, Netherlands, and North America.

Barkatsas, Carr, and Cooper have developed a thoughtful resource for those who are beginning in their STEM education journey or are looking for different ways to incorporate STEM principles into an existing program.

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