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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?

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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.

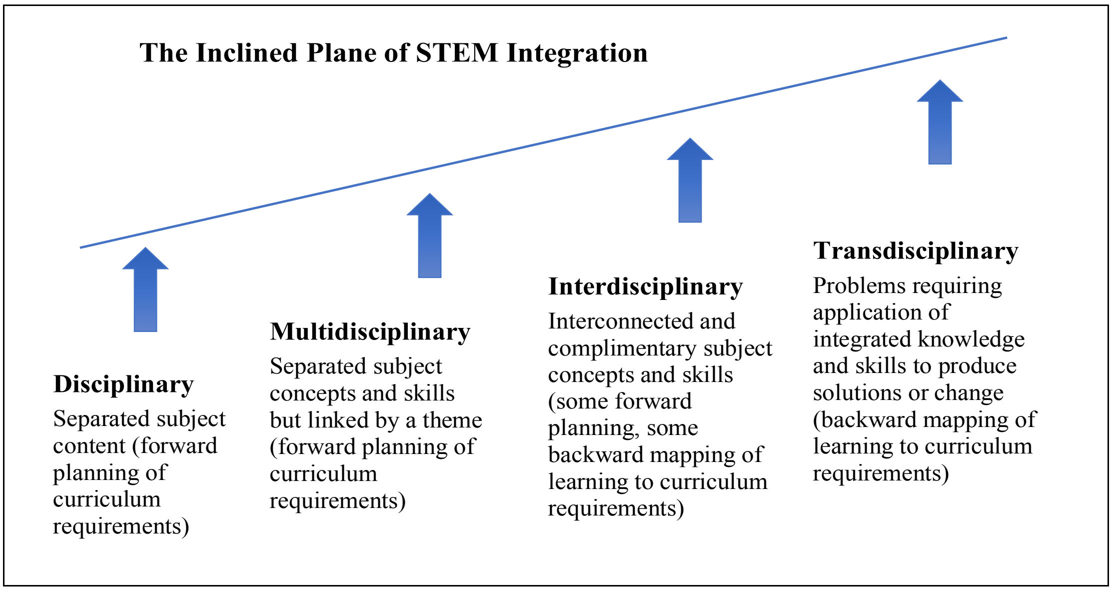

Figure 1. A continuum of STEM integration adapted from Vasquez (2015, p. 13).

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).

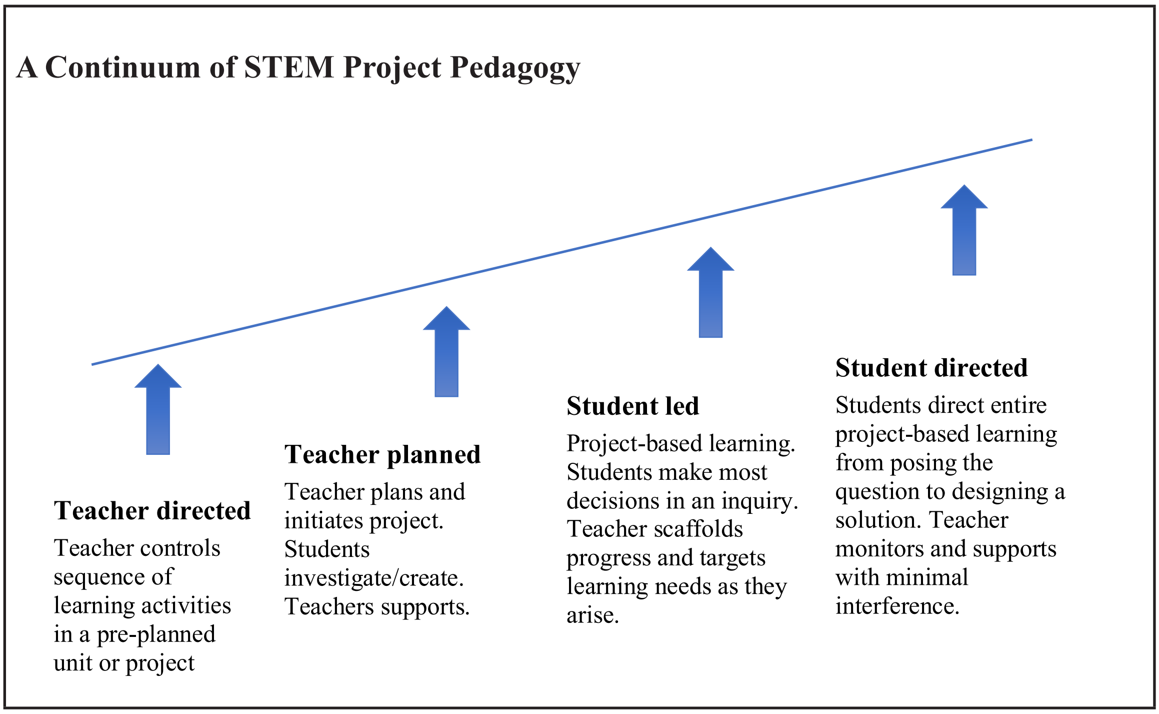

Figure 2. A continuum of STEM project pedagogy

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.

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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

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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

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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).

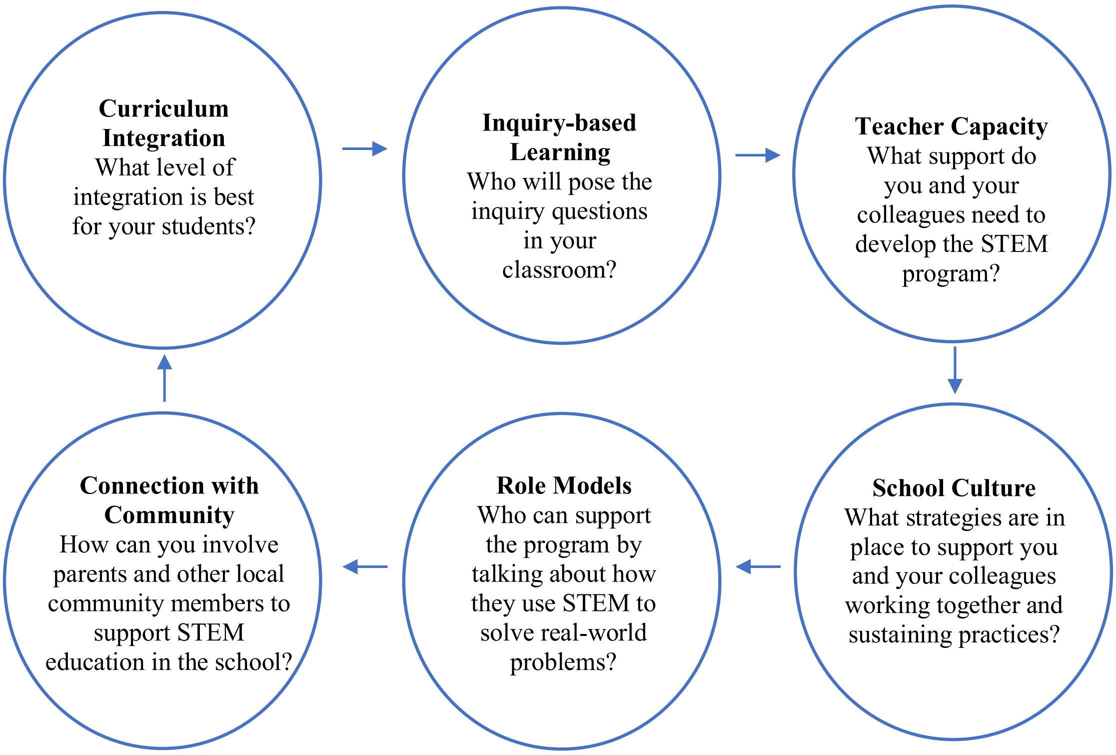

Figure 3. Proposed model of key characteristics of an effective integrated STEM program.

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.

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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

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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

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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; $^*P<.05$; $^{**}P<.01$

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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).

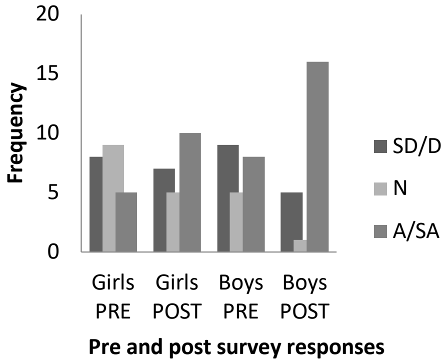

Figure 4. Students' responses to the prompt "it would be exciting to be a scientist" from strongly disagree [SD] to strongly agree [SA]

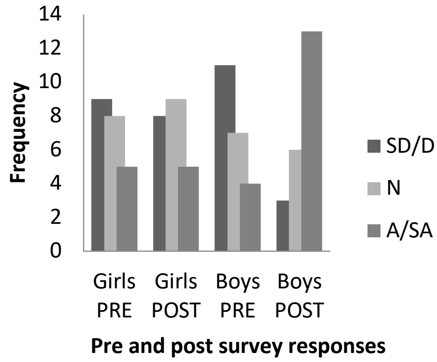

Figure 5. Students' responses to "it would be exciting to have a job working with maths" from strongly disagree [SD] to strongly agree [SA]

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 ($n=22$).

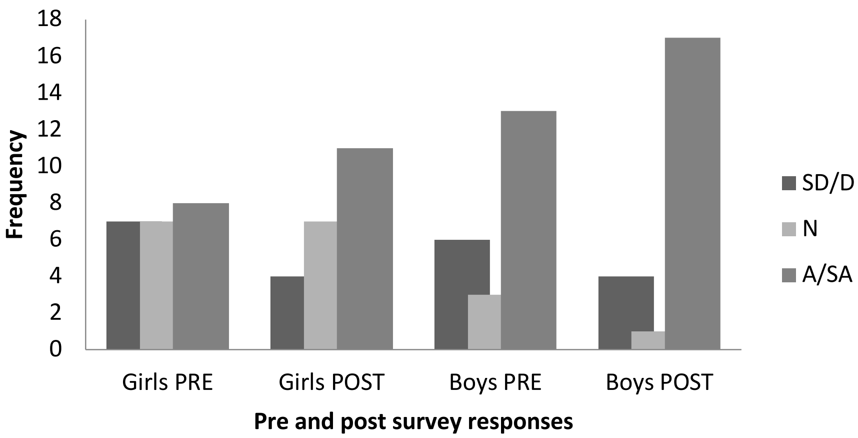

Figure 6. Students' responses to "it would be exciting to have a job working with technology" from strongly disagree [SD] to strongly agree [SA]

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

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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

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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.

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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

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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™ (https://www.sphero.com/education/) and Bee-Bots™ (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

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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

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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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