Chapter 23

Integrated STEM in Australian Public Schools: Opening up Possibilities for Effective Teacher Professional Learning

Jane Hunter

University of Technology Sydney, Australia

Abstract Building teacher agency in teaching and learning in Science, Technology, Engineering and Mathematics (STEM) is recognized as a significant challenge for school education systems in Australia and across the world. Reform initiatives will require substantial changes in how the STEM disciplines are taught at school and in professional learning for in-service teacher education. In this chapter I examine how a qualitative research study in three elementary schools in a large education jurisdiction in Australia used a pedagogical framework and action research to support changes in STEM teaching and learning in classrooms. The findings are presented in a case study, *Windows into STEM*, which examined how teachers who collaborated in school-based teams increased their content knowledge in multiple subjects as they experimented with new pedagogies that disrupted their beliefs about the enactment of integrated STEM in elementary classrooms.

Key words: STEM education, High Possibility Classrooms, pedagogy, teacher professional learning, integrated STEM.

23.1 Introduction

The challenge of integrating Science, Technology, Engineering and Mathematics (STEM) disciplines into teaching and learning in school education is well documented in the education literature (Beane 1997; Bybee 2018; Shernoff, Sinha, Bressler & Ginsburg 2017, Zollman 2012). Concerns range from inadequate preservice teacher education programs; lack of in-service teacher confidence in the STEM disciplines; the 'siloed' nature of curriculum in schools (especially in senior [secondary] schools); crowded timetables; few resources and too little time to engage with STEM teacher professional learning; outmoded approaches to classroom pedagogy; the lack of popularity of the four disciplines; and then the notion of STEM being a 'fad', with the attendant impression of a 'STEM crisis' in school education (Thibaut et al. 2018; Tytler, Osborne, Williams, Tytler & Cripps Clark 2008). In this chapter I reflect on such concerns in the context of building teacher agency and professional development in a STEM research project conducted with teachers in Australian elementary schools. Here, *professional learning* refers to the processes and experiences teachers engage with to develop their practice; while *professional development* describes structured learning activities for teachers, sometimes one-off but preferably ongoing and well resourced.

Apprehensions surrounding STEM education also populate discussions of school education in the mainstream media in Australia, the United States and parts of Asia and Europe (Kelley & Knowles 2016; Moore, Johnson, Peters-Burton & Guzey 2016; Smith 2018). Education jurisdictions are charged with raising national productivity using measures like GDP in their countries because of a perceived 'STEM drain' and the decline of students' scores in standardised international tests, notably the cycles of PISA (Program for International

Student Assessment) and TIMSS (Trends in International Mathematics and Science Study). Both testing systems are the subject of considerable political controversy and debate in many countries (Koziol 2018; Lin, Lin, Potvin & Tsai 2018) and it often seems that every business leader, political elite and social media commentator has an opinion about STEM education (Berry 2018; Light 2018). Both the National Research Council (2012) in the United States and the Organization for Economic Co-operation and Development (2012) suggest that reform initiatives focussing on STEM will require substantial changes in how the four disciplines are taught, not only in schools but also in university preservice teacher education courses and in professional learning opportunities for in-service teachers (Chapman & Vivian 2017; Timms, Moyle, Weldon & Mitchell 2018).

Terms used concomitantly with STEM are 'integrated curriculum' and 'integrated STEM', both of which also stimulate debate (Williams 2011). For example, in recent reflections on the Australian Curriculum (AC), Mockler (2018) suggests that curriculum integration is not a new idea and a renewed focus on STEM might be just the innovation needed for furthering curriculum integration and developing students' capacity and knowledge across disciplinary boundaries. Integration may be multidisciplinary (content from disciplines linked to a chosen theme), interdisciplinary (different disciplines focused on skills) and transdisciplinary (using big ideas to drive natural connections between the disciplines). These approaches to curriculum offer rich support to students in ways that may lead to increasing numbers of them graduating from STEM courses in post-school education (Beane 1997; National Academy of Engineering and National Research Council 2014). As well, in a promising advance in education in senior schools, Thibaut et al. (2018) cite integrated curriculum as demonstrating improvement in students' interest in STEM and their subsequent motivation to extend this interest beyond isolated study of the four disciplines.

The research examined in this chapter comes from a case study, *Windows into STEM*, which involved elementary teachers in three schools in one Australian education jurisdiction. It adds to findings from a replica STEM study (Hunter 2017) conducted 12 months prior. In both studies, 'integrated STEM' refers to a pedagogical approach whereby a teacher or a team of teachers adopted a pedagogy for STEM teaching and learning that blends multi-, inter-, and trans-disciplinary approaches involving big questions, significant problems and complex ideas. Participating teachers drew on the natural connections between Science, Technology, Engineering and Mathematics offered by the *High Possibility Classrooms* (Hunter 2013; 2015a, b) framework alongside inquiry-based learning (Murdoch 2015) to develop, units of work, programs and/or design challenges that gave equal attention to the four disciplines. The rationale for a pedagogical approach to STEM arises out of a call to action by Tytler et al. (2008) in their influential literature review:

> Pedagogy … will strengthen the intellectual rigor of STEM learning and interest students in STEM content from kindergarten until the end of secondary [senior] schooling.… [It] is the critical element in enlisting student engagement with STEM subjects. (pp. vii-ix)

There are five remaining parts to the chapter. In the first part, I illustrate how action research combined with the *High Possibility Classrooms* (HPC) pedagogical framework developed from the practices of Australian teachers (Hunter 2013; Hunter 2015a, b) informed effective teacher professional learning in STEM. In part two, I discuss STEM education in Australian schools and examine particular claims and ideas for more contemporary approaches to teaching and learning. The third part sets out the study design, research question/s, method of data analysis and limitations of the *Windows into STEM* case study. Evidence from this study is built upon contextually relevant professional development (PD) activities in curriculum integration that occurred when teachers deliberately brought all four disciplines together through active attention to pedagogy. Part four describes the findings from the case study. It briefly illustrates how students experienced integrated STEM and details how the HPC framework, which included a workshop and a final sharing session, informed new approaches to teaching and learning in the participating teachers' classrooms. In the concluding part of the chapter, I reflect on how these elementary teachers, when focused on pedagogy, fostered powerful integrated STEM teaching and learning that moved beyond 'solo subject lessons', and 'one-off' projects.

23.2 The *High Possibility Classrooms* Framework and Action Research as Key Drivers for Designing Integrated STEM

The HPC framework for teaching and learning builds on the Technological Pedagogical and Content Knowledge (TPACK) framework developed by Mishra and Koehler (2006). Importantly, justification for the use of the HPC framework for integrated STEM in this research study arose from the challenge offered by Tytler et al. (2008) mentioned earlier. In other words, STEM pedagogy needs to change.

The framework was specifically developed from research into exemplary teachers' knowledge of technology integration in classrooms in Australian schools (Hunter 2013). It was subsequently validated in studies that did not have a purposive sample of participants like those in the original study. Findings from these more recent studies demonstrate that HPC moves beyond technology knowledge in that it supports the motivation and development of teachers' content knowledge in STEM subjects and other curriculum domains. When content or discipline knowledge is combined with pedagogy involving various technologies (both as hardware tools and software programs), it motivates teaching and learning in more student-centred ways (Hunter 2017; Jefferson & Anderson 2017). With HPC, classroom practices involve but are not necessarily reliant on technology integration as the means of bringing together a range of curriculum areas around a theme, a big question or a complex idea (Bonfiglio-Pavisich 2018; Groundwater-Smith & Mockler 2015; Hunter 2019; Lin et al. 2018; McGowan 2018).

The five conceptions of the HPC framework are *theory, creativity, public learning, life preparation,* and *contextual accommodations* (see Figure 1). These form a scaffolded set of instructional techniques and student learning processes that makes pedagogy the key to teachers' knowledge and enactment of technology integration. Each of these conceptions is underpinned by a series of themes (see Table 1). For example, the first conception, *theory* may be expressed in the following way:

> Teacher's technology philosophy in the classroom affects practice, and is supported by various themes: the construction of learning, purposeful teaching, and planning … through implementation of these themes, the teacher's knowledge and actions impact students learning processes of enriching the subject matter … reflective learning and shifting their conversations and thinking … it therefore engages students in authentic ways. (Hunter 2015a, p. 150).

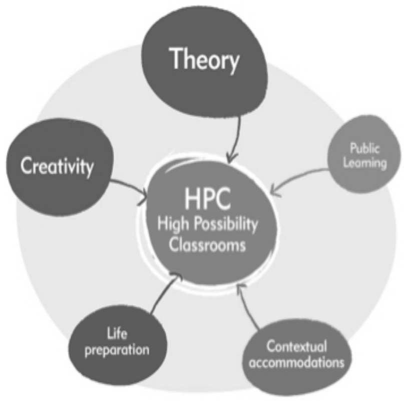

Figure 1. High Possibility Classrooms framework featuring the five conceptions (Copyright Jane Hunter 2015)

Table 1
The Five Conceptions and 22 Underpinning Themes of the HPC Framework

Theory driven technology practice	Creativity for learning through technology	Public learning through technology	Life preparation using technology	Contextual accommodations using technology
Technology drives the construction of learning	Technology boosts creativity	Technology scaffolds performance	Technology operationalizes the real world	Technology remains personal and professional
Technology enhances purposeful teaching	Technology creates opportunities for production	Technology enhances outcomes	Technology gives voice	Technology changes time
Technology focuses planning	Technology unleashes playful moments		Technology means ownership and possibility	Technology nurtures community
Technology enriches subject matter	Technology supports values		Technology reveals effectiveness	Technology defines the game
Technology promotes reflective learning	Technology differentiates learning			
Technology shifts conversations and thinking				
Technology engages students in authentic ways				

(Copyright Jane Hunter 2015)

The remaining four HPC conceptions are potent for describing how teachers' knowledge of technology integration can be actioned in various subject domains, including an integrated approach to STEM (Hunter 2017). The second conception, *creativity*, refers to boosting learning through technology, creating opportunities for production, unleashing playful moments, supporting the teachers values and enabling differentiation of learning. In *public learning*, the third conception, technology scaffolds the performance of students' work in front of peers or for online audiences, thereby enhancing their learning outcomes. The fourth conception, *life preparation*, reminds teachers that technology is operationalised in the real world for students, giving them a voice, ownership and responsibility, and engaging and motivating them. In the fifth conception, *contextual accommodations*, teachers' technological integration is acknowledged as both personal and professional, capable of nurturing the whole community.

The HPC framework's effectiveness for teaching and learning in STEM in K–12 classrooms is enhanced when it is supported by a program of professional learning that incorporates collaboration and opportunities for reflection on practice and draws on an academic partnership with a trusted outsider (Hunter & Mitchell 2011; Littlejohn 2016; Smits, Voogt, & van Valze 2019). The *Windows into STEM* case study of three elementary schools used action research methods that would be familiar to those acquainted with the professional learning activities of teachers (Groundwater-Smith 1988; Mockler & Sachs 2011). Kemmis and McTaggart (1988) define action research as:

> a form of collective self-reflective enquiry undertaken by participants in social situations in order to improve the rationality and justice of their own social or education practices, as well as their understanding of these practices and the situations in which these practices are carried out. (p. 1)

Kemmis (2011) makes it explicit that action research is participatory, undertaken

> collectively by participants in social practice to achieve 'effective historical consciousness' … of their praxis as practice – that is a morally informed, committed action, oriented by tradition that responds wisely to the needs, circumstances and particulars of a practical situation. (pp. 13-14)

Campbell and Groundwater-Smith (2010) draw distinctions between technical, practical and emancipatory action research. Underlying these distinctions is a commitment to improving practice, with teacher participation sometimes involving feelings of vulnerability as a consequence of critical reflection and self-evaluation. Such reflexivity aligns with the notion of 'insider knowledge', which, in combination with the 'outsider knowledge' of an academic partner or external colleague who supports and sometimes challenges the teacher's classroom practices, can lead to powerful teacher professional learning (Kirkby 2015; McWilliam 2009).

Prior to describing the research design, it is necessary to place this study within the broader context of STEM education in Australian schools.

23.3 STEM Education in Australian schools

For more than a decade the 'STEM crisis' has been a refrain in public commentary about education in Australian schools (Berry 2018; Rosicka 2016). Whether or not there is in fact 'a crisis', the discourse surrounding it is often driven by media attention fed by utilitarian and political agendas unrelated to education per se but to which educators are expected to respond, even to the extent of their narrowing the interpretations of STEM education to the detriment of learners (Blackley & Howell 2015). However, recent research demonstrates that Australian teachers are rising to the challenge of fostering student interest in STEM, especially in elementary schools (Timms et al. 2018; Wall 2016). To suggest therefore that perceived faults with STEM education result only from ‘teacher weakness’ or ‘inadequate teacher education’ is to underestimate the nature of the situation today (Mockler 2018).

Since 2012 the Australian government’s Office of the Chief Scientist has emphasised the urgent need to advance societal knowledge in STEM (Prinsley & Johnston 2015). Central to such arguments are research data stating that too few students are taking higher levels of mathematics and science in secondary schools (Prinsley & Johnston 2015); too many STEM teachers are either unqualified to teach the disciplines well (Varadharajan 2017) or are in an ageing cohort (Audit Office of New South Wales 2019); and that efforts to maximize end-of-school results by taking STEM subjects may come at the expense of scoring well to gain university entrance (STEM Partnerships Forum 2018). While the STEM conversation has mostly revolved around senior (secondary) education in Australia, there has been increasing recognition that interest in the STEM disciplines needs to start from the early years of schooling, with programs like Little Scientists (2019), which targets children from three to six years of age, funded by the Australian government. It has also been noted that opportunities to participate in STEM should not need to depend on pre-schooling experiences or access to out-of-hours enrichment activities (Moomaw & Davis 2010).

Prinsley and Johnston (2015) outline steps “to make great teaching of Science, Technology and Mathematics the norm in Australian schools, and teaching a profession of choice” (p. 1) by attracting high achievers in STEM to school teaching, boosting the rigor of university preservice teacher education courses, and ensuring that STEM education is supported by specialist teachers, professional development, and the education of principals to be leaders in STEM. These recommendations are echoed in the Australian government’s endorsement of the 10-year *National STEM School Education Strategy 2016–2026* (Education Council 2015), which has two goals:

1. Ensure all students finish school with strong foundational knowledge in STEM and related skills.
2. Ensure that students are inspired to take on more challenging STEM subjects. (p. 5)

Goals like these support students’ ability, engagement and aspiration for STEM subjects; teacher capacity and the teaching quality of STEM in classrooms; more STEM education opportunities within school systems; effective partnerships with tertiary education providers, business and industry; and the building of a strong evidence base (Department of Education and Training 2018). Fulfilling such goals, however, requires not only curriculum change but also the delivery of both funding and time for teachers’ professional development (Ringland & Fuda 2018). Keen to make its STEM priority known, in 2015 the Australian government announced its National and Innovation Science Agenda (NISA 2015) and committed funding of more than AUD1.1 billion to it.

Another concern for STEM educators is the under-representation of girls in STEM, not only in the latter years of senior schooling but also in university classes. One recent study reported in *Girls Future Our Future* (Hobbs et al. 2017) found that participation rates of girls in STEM, particularly in physics and advanced mathematics, have remained unchanged or declined since the mid-1990s. Factors like providing quality career advice, changing the teaching and learning environments, working with teachers on their pedagogy, creating partnerships with industries and local communities, and funding through state and federal jurisdictions are critical for supporting girls. Chapman and Vivian (2017) found that particular stakeholder areas play key roles in girls choosing and staying with STEM, for example, girls-only opportunities, family involvement, authentic connections, and practical STEM programs that target girls with effective and inclusive messaging.

This consistent message for an equity-driven vision for STEM education in Australia requires collaboration across prominent bodies; strategies that generate an unbiased culture of STEM; a balanced representation of all groups within the STEM ecosystem; engagement from early childhood through to professional leadership; curricula that empower students in learning choices, including mentoring and capacity building through professional opportunities (English 2016); and grassroots activism that values and advocates local ideas (Hobbs et al. 2017). Having touched on these ongoing challenges for STEM education in Australian schools, let us turn to the research design that underpins the *Windows into STEM* case study.

23.4 Study Design

The author was approached to conduct the study by the school principals after an address at a state education conference. The participating schools funded the research and the university ethics committee and the state education regulator approved it (all approval numbers are available on request). Case study methodology (Stake 1998) was used to address the main research question:

> How does a pedagogical framework like HPC facilitate the development of integrated STEM approaches to teaching and learning?

Two sub-questions underpinned the core focus:

1. What are the innovative integrated STEM strategies that teachers use?
2. What fosters or constrains teacher professional learning in integrated STEM?

Participants began the study in a whole-day HPC workshop facilitated by the author. The workshop explored the conceptions and themes of the HPC framework (see Figure 1 and Table 1), provided participants with STEM resources and links to experts who could support content knowledge in the disciplines, and introduced them to a bespoke online community designed to facilitate their ongoing commitment and connection to the study. In addition, the workshop engaged with learning-stage syllabus documents of the four STEM disciplines. The E for engineering is not a key focus in the elementary curriculum in Australia, and at each school in the study it was often satisfied through attention to ‘making’ or the ‘use and design of specialised equipment’ such as measuring water salinity, cultivating plants in garden beds, or using a hydraulic water pump.

Throughout the study, participants followed a process of planning, acting, and reflecting, with the ultimate goal being sustainable change in practice (Grundy & Kemmis 1982). Through individual and collective interviews in teams (N = 13), teachers in three low socio-economic status schools that have high numbers of students from English as an Additional Language or Dialect (EAL/D) families reflected on their own practices and gave regular feedback on each other’s teaching.

A total of 525 students participated. With action research, action learning and academic partnership framing the case study design, the author as the academic partner observed 29 classrooms and collected school STEM policies/artefacts along with the seven integrated STEM units of work/programs/design challenges that were developed. She also conducted six focus groups interviews with 45 students from the teachers’ classrooms chosen with balance of age, gender and ability.

Qualitative data were analyzed in four stages:

1. Summaries were made of field notes, classroom observations and policies/artefacts/documents.

2. Transcription and member checking of all interviews and focus groups were carried out.
3. As with all HPC research to date, *NVivo 11* was used for data analysis, building on the original codes and themes (Hunter 2013).
4. There was a cross-case sharing meeting in which notes made during each team's presentation were subsequently used to triangulate preliminary findings.

A limitation to this research concerns the long-term sustainability of integrated STEM and the degree to which pedagogy impacts student learning outcomes, including how it's reported in annual assessments and portfolios. Key findings of the case study will now be presented as "an opportunity to learn" (Stake 1998, p. 89).

23.5 Case Study: *Windows into STEM*

> When I integrated STEM and paid attention to each of the disciplines it was often not easy because I felt I was forcing it as the school day is not set up that way. By preparing a mindful unit of work it now means I teach in a different way. The atmosphere in my classroom changed from me out the front to a focus on students. (Susan, from Lorimer Public School)

This quote from Susan (all participants and sites have pseudonyms) identifies how the process of integrated STEM presented itself as a 'mindful unit of work', where each of the four STEM subjects was considered deliberately and attentively, all the time drawing from syllabus outcomes mandated by the education jurisdiction. It also highlights how when school structures like timetables and reporting don't maximize the integration of multiple subjects it can feel 'forced'. Susan perceived a change in her pedagogy from a didactic approach to one that was more student-centered, and when questioned on this point in focus groups her students said they preferred it too.

In the case study, the HPC workshop was the impetus for professional learning in integrated STEM. It was a professional development (PD) activity that introduced the teachers to thinking differently about teaching and learning when integrating the four subjects. This case study featured the schools, the teachers' classrooms and students, and the central innovations that supported integrated STEM in teaching and learning. Moreover, it showed whether HPC would support or hinder the planning processes of integration and what, if anything, might optimize or constrain teacher professional learning in integrated STEM. It also shed light on co-teaching, how much curriculum work is cherished by teachers as 'professional work', how successful achievements in teaching and learning build teacher confidence; and how integrated STEM might deepen student engagement if the structures of the school day were to facilitate longer blocks of learning time.

23.5.1 The Schools

Three elementary public schools, Lorimer, Blossom South and Myrtle Hill, are in the south-western suburbs of a major Australian city; the sites belong to a community of schools that has a network of active principals. There are significant numbers of EAL/D students (83% to 98%) in the schools, in addition to 'refugee and new arrival' students. A few teachers (<10%) found the metalanguage required for these students acted as a significant barrier to be overcome in integrated STEM; they had to change their approach and often broke down concepts into "smaller learning chunks", as this was the only way to support clear understanding:

> EAL/D students find STEM harder because of their low literacy/numeracy levels – perhaps the question I need to ask myself is more about: 'How can I as the classroom teacher change what I

am doing to better scaffold/meet the learning needs of EAL/D students in STEM?' (Sally, from Blossom South Public School)

Technology resources in classrooms at two sites were limited but what was apparent in all three schools was the lack of technical kits, scientific tools and electronic resources. For example, students habitually had to dismantle structures so that another class could use the same circuits or batteries. This comment from a student suggests frustration with the lack of resources and physical classroom space:

> I didn't like packing up. Then we had to rebuild it again and again; other classes need to use our stuff. It was time consuming. I didn't like how my friend kept stepping on our project. Maybe putting a sign up or maybe the teacher should have helped out. We need shelves in our rooms. (11-12 year old student)

While most classrooms were old, some schools were involved in rebuilding projects as part of a government priority. However, frequently the rooms were too crowded for all the students to be comfortably accommodated, and the Wi-Fi access was often unreliable.

23.5.2 The Teachers

The 21 participating teachers ranged in teaching experience from 18 months to 30 years. For the purposes of the case study, they worked in small teams in a learning stage to integrate each of the STEM subjects using three or more HPC conceptions and themes. For example, when dealing with the conception of *creativity*, teams thought about the ways integrated STEM teaching and learning could be used to make or create products (i.e. it provided opportunities for production and/or to differentiate content for students).

Each unit/program/design challenge was planned for 10 weeks or one school term and used a scaffold or inquiry-based learning template developed by the author that is reflective of the work of Murdoch (2015) and Munns, Sawyer and Cole (2013). Table 2 details the seven STEM units/programs/design challenges with their big questions/key themes. Each unit was also framed by an overarching question/big idea, which was then broken down into a series of three sub-questions/smaller ideas. It often started with a hook activity to arouse interest, then within each sub-question students used a process of gather, organize, analyze, synthesize and apply. The unit/program/design challenge concluded with a culminating activity, which invariably involved a presentation to parents, other classes, the whole school, system personnel, or an expert panel of industry partners.

Table 2
Details of Each Teaching Team's Integrated STEM Unit of Work/Program/Design Challenge

Public school name	**Name or title of the integrated STEM unit of work/program/design challenge; Theme; Big idea/ question; Stage 3 (11–12 years old); Stage 2 (9–10 years old)**
Lorimer	Stage 3: Earth's place in space: How is life supported on all the planets? Stage 2 Design: How are our everyday products made?
Myrtle Hill	Stage 3: Sustainability: How has the XXXX (local) River changed over time? Stage 2: Climate change: How is our world growing and changing?
Blossom South	Stage 3: Light/Electricity: How has electricity made a difference in society? Stage 2: Motion and physics: How do forces shape how things move?

One teacher described her experience of integrated STEM using HPC this way:

> When I teach the students a concept about something – they think of it in a narrow way. I try to break them out of that narrow way of learning - that box. Applying knowledge they have already acquired to this lesson. This had been a really interesting process. They need to figure it out for themselves. (Eva, from Myrtle Hill Public School)

Eva's comment reflects a common experience articulated by the majority of teachers (>80%) when they integrated content and skills from four disciplines; a typical description is of "almost forcing students to think across disciplines and recall learning from previous lessons or make their own connections". The dominant perception in interviews was of teachers leaving students to struggle with the understanding of a concept/s before 'jumping in' to give them the correct answer. Reservations about STEM expressed by a preponderance of teachers/teams in week four interviews reflected their focus on "lack of subject matter knowledge", and "finding good stage-level resources". By the second round of interviews in week eight, these concerns had given way to expressions of greater confidence in the content they were teaching, especially in Mathematics and Science, and a greater familiarity with the HPC framework and the inquiry process for planning. This revelation from Laurie is typical of most:

> I am doing a lot of extra study if the subject matter is not known to me or it's vague. It's a chance to refresh things I don't know or haven't taught for a while. And, I don't want to get caught out if a student asks me something I don't know. I have used the online resources and I asked an expert to come in. (Laurie, from Blossom South Public School)

23.5.3 The Classrooms

Numbers of students in classrooms varied from seven in a support unit of high-needs students to larger classes of 32. Often teachers in each stage would co-teach as teams, which meant creating larger groups of students, for example, 11- to 12-year-olds (N=64) "cramped into one space". In some schools, when it was "STEM time" the teachers used the library space or opened adjoining classroom spaces.

In Table 2 the units/programs/design challenges caption suggests a Science bias; the other disciplines were added in during the planning process. Many teachers had existing units from *Primary Connections*, a popular Science program in the jurisdiction (Australian Academy of Sciences 2018). Most wanted to re-work existing units or felt that using them was a base-point platform to scaffold a "new way of teaching more disciplines". Once the teams started to add in all four subject outcomes from the syllabus documents alongside the HPC conceptions and themes, the teaching in most classrooms became noticeably more "hands on" and "student centered". The following remark captures one teacher's growing confidence in integrated STEM; her sentiment was frequently echoed by other teams and noticed in classroom observations in the latter stages of the study:

> I think it is a better way to teach. I'm also getting what it means to integrate. It's really engaging for them and student centred, they are there to discover their own learning … you are just facilitating their activities and they can discover the information they want for themselves. Instead of turning off they are engaged. (Gordana, from Myrtle Hill Public School)

However, by the end of the data collection period there was still a minority of teachers (<10%) that found integrated STEM problematic, and "too time consuming", as demonstrated in this comment:

> I hoped they [the students] might get into a new way of learning straight away but they didn't. The thing is teaching this way is so different. It's as if really unstructured work needs a whole lot of planning structure. And yes, there was a lot more time spent on integrating all the STEM subjects. (Cynthia, from Lorimer Public School)

23.5.4 The Students

Students at all three schools liked integrated STEM because it gave them opportunities to make and create products using their hands, increased their chances of making new friends when working with larger groups of peers, and made the learning "more authentic" when they used the real equipment of STEM. These four comments were typical of students:

> It is better to work in groups because more people have things in their head and so you all benefit together as a team because you cooperate.

> We prefer to do our projects by ourselves. It is better for our future - that is the good thing with hands on learning.

> Collaborating together and making new friends and exploring other people's ideas is my favourite.

> We got to make different types of circuits. I could actually do that without the teacher now so my confidence has really improved.

By the study's end, a minority of students (<7%) remained critical of integrated STEM, their concerns mainly to do with their "teacher's explanations" and "not moving on quickly enough when setting out instructions". Concerns around "never having enough time" were expressed by many students, with some suggesting that the school timetable be adjusted to allow more time for STEM. Their favorite lessons were those where 'chain reactions' were constructed, including the creation of simple circuits, page-turners, and a complex tooth-brusher. They enjoyed the challenge of using water-testing kits, microscopes, and digital temperature recorders. One student spoke at length about the classroom being "much noisier now" and that "pressure of working a team" brought out her competitive spirit. Some believed that integrated STEM brought a welcome change to the way the four subjects were previously taught by their teachers:

> When we leave elementary school we will do group activities … there will be engineering, we know how it works and how to work together and do research into problems … this will give me a head start.

Another student suggested that his learning experience this term had been so meaningful that he wanted to become a STEM teacher in a senior (secondary) school: "This is the way these subjects should be taught all the time." My observations confirmed consistency with what students articulated in focus groups and how they worked in teams and classrooms.

23.5.5 The Strategies/Approaches

Innovative strategies and processes for integrated STEM

Participating teachers recounted their successes in particular areas, giving specific examples of what supported them to integrate STEM using the HPC pedagogical scaffold, and referring most often to three of its conceptions and themes: creativity, public learning and life preparation. Observations revealed that integrated STEM teaching and learning regularly involved a range of technology resources, assessment/presentation strategies, and innovative student learning processes. The following 10 were significant:

1. IGNITE style presentations
2. Exit tickets as an integral part of assessment
3. Edmodo blogging tools
4. Seesaw
5. Twitter (most had set up a class account)
6. Weebly sites
7. Google Classroom

8. Canva
9. One Note
10. Bitcoin ledgers/Blockchain.

In regard to the use of Edmodo, one teacher said:

> The formative assessment part when integrating STEM was assisted by using Edmodo. It allowed me to see the whole class in a snapshot and track how they move on from one content area to another – I can see what they have understood. (Jay, from Blossom South Public School)

Setting up a STEM station in classrooms was a common pedagogical strategy; so too was assigning roles for students to work in STEM teams as a Scientist, Technologist, Engineer or Mathematician. An expression of success is unmistakable in this comment from a teacher who was keen to add more content areas:

> [The students] were so engaged all the time … our goal now is to teach everything through STEM – fitting in English and History too. It is good to make lessons longer to do integrated STEM justice. (Beavis, from Blossom South Public School)

The teachers' integration of the STEM subjects mainly involved 'hook lessons' such as using green screens and iMovie software and staging a Product Fair. Students created "Farmbot-style" devices; wrote code; used testing kits; created an outdoor light show; went on excursions to significant sites; made documentaries for a school film festival; used real-time data collected in graphs and calculations at the local river; created Rube Goldberg machines; showcased STEM in front of the whole school; and conducted lunchtime rubbish audits. One team of teachers held a STEM workshop for parents, and another "invited in experts" from local industries and universities.

Fostering and constraining integrated STEM using the HPC framework

The whole-day PD workshop on HPC conducted by the author was held at the end of the school term prior to the commencement of data collection scheduled for the following term. This PD activity involved all teachers completing a pre-intervention survey (findings of these data are reported elsewhere); a brief lecture-style presentation on the HPC framework and the action learning cycle and processes; a series of hands-on STEM activities targeting principles of physics, engineering and mathematics (for example: calculation, mapping, and data tasks) involving the author's colleagues; logging onto the online HPC community created for the study; and an afternoon session devoted to planning an integrated STEM unit of work/program/design challenge using the template developed by the author. Resources, papers and online materials about HPC, action learning, and STEM were circulated prior to the workshop and made available online; these were added to over the research period, with teams of teachers uploading photographic records of their students' work and chronicling other classroom STEM activities.

Most teachers said the most enabling aspects of the initial PD were the opportunities it provided to "*renew practice for their professional growth*", to "*start a personal focus on integrated STEM in teaching and learning*", and to "*experience and experiment with teaching in less student-centred ways*". Here is a typical comment:

> We have a culture of delving into theory into teaching practice in my school so delving into that in the workshop was very important to us. (Sue, from Lorimer Public School)

However, regarding the PD experience, a minority of teachers (<10%) felt that it did not go far enough, with these teachers wanting

> more time to plan units/programs on the day, and access to additional examples from research (Jenny, from Blossom South Public School)

> to meet up again to collaborate with other schools to check their colleagues' development of the integrated STEM units/programs/design challenges. (Brett, from Myrtle Hill Public School)

In the final week of the study a second and final sharing session was held to circulate preliminary findings and to enable each team to distribute their work and talk about what they had learned from the professional learning experience. All teams attended together with the school principals and senior management from within the education jurisdiction. Observations and recordings from this final meeting are replete with comments from teachers who had "initially struggled with aspects of the study's remit" and by the end of week 10 were able to share many positive experiences of integrated STEM. The following statements speak to the 'highs and lows' along the way:

> In terms of confidence it has been really good to work together in a team and this has boosted my confidence. We nutted things out and spent a lot of time working on the unit to integrate the subjects well. Students also saw good modelling with us working together and we love that they go home very excited about their STEM learning. It feels great and it has built the students confidence and ours as well. (Janine, from Blossom South Public School)

> I had to do a lot of research to thoroughly understand the concepts I was teaching. I had to make resources. In one topic we taught I thought this knowledge is so important … why don't people do this anymore … that was really exciting. (Tina, from Myrtle Hill Public School)

With the case study *Windows into STEM* now concluded, the implications of the research for the professional learning of teachers in elementary schools will now be reflected upon.

23.6 Reflections on Pedagogy, Professional Learning and Integrated STEM

Integrated STEM that is contained within a program of research focussed on pedagogy has the potential to support teacher professional learning in ways not possible with one-off PD experiences and passive activities outside the school context (Yoder, Bodary, & Johnson 2016). For most of the teachers in this study, however, professional learning designed in tandem with a qualitative research study was a new kind of PD experience, and what they were asked to do was multi-layered and ambitious. Those who found it challenging sometimes looked to the author (as the academic partner) to provide practical solutions to problems or examples of 'what works' (Shernoff, Sinha, Bressler, & Ginsburg 2017; Wiggins & Tighe 2007).

Concerns reported by fewer than 10% of participants were time constraints, the insufficient provision of integrated STEM examples, and the management of the ongoing workload of integration, all of which are consistent with 'best practice requests' in other studies (e.g. Glancy et al. 2014; Kelley & Knowles 2016; Shernoff et al. 2017). Sustaining changes to practice after the completion of the PD events was also difficult for some teachers, particularly if they had no time for ongoing contemplation (Kirkby 2015; Meier 2002; Mockler 2018). Fortunately, I can report that most teams at the three schools in this case study have continued their work in integrated STEM, with many adding Arts [and Humanities] subjects to make it STEAM.

The findings of this research study show that integrated STEM using the HPC framework optimised teacher agency and professional learning in four main ways.

1. It acted as a scaffold for practice that created pedagogical accountability for planning, programming, and content in existing and new units of work/programs/design challenges.

2. By deliberately embedding conceptions and themes from HPC, teachers could focus on content using technology-enhanced pedagogy that students found more engaging and motivating than previous approaches to the subjects.
3. It provided a natural fit with project-based, design-based, and student-centred learning that effectively linked integrated STEM to problem solving, higher order thinking skills, and real world concerns.
4. It fostered collaboration across classrooms and allowed teachers to build personal confidence and work more effectively in teams to plan and systematically integrate the four subjects.

A core insight from the *Windows into STEM* case study resonates with what Timms et al. (2018) recommend for developing an integrated STEM curriculum in Australian schools:

> If STEM is to be truly implemented, curriculum designers will have to address how to ensure all parts of this challenge are addressed and cope with defining the knowledge and skills necessary for each discipline in a durable way that is able to accommodate future changes in disciplinary knowledge and scope. The design will have to account for the limited space in the overall curriculum and assessment systems will have to reflect the breadth of STEM. (p. 12)

Most school structures are quite 'siloed', and even in elementary schools where teachers are deemed generalists because they teach at least six key curriculum areas, subject integration or project-based learning is not reflected adequately in school reports and other assessment tools. Schools would need to do fewer of their regular activities if integrated STEM were to be given the status of adequate time and the timetabled priority it deserves. However its effectiveness would most likely be impeded by relegation to a weekly session, small solo projects, or a series of single lessons. In the US, the Next Generation Science Standards (nd) has taken up this challenge, as has Denmark with its KOM Project (Niss 2015) and the UK, where the General Certificate of Secondary Education offers Engineering as a subject choice in its own right (National Assessment Governing Board 2014). Such examples point to what will ultimately be required for a living, integrated STEM curriculum in Australia.

In a recent development, Thibaut et al.'s (2018) *Systematic Review of Instructional Practices in STEM* has explored integration of STEM content, problem-centered learning, inquiry-based learning, design-based learning, and cooperative learning. Set within a social constructivist view of learning, this is the closest example I've seen so far of what integrated STEM might be. It holds exciting promise.

What is apparent from the many new conversations about the need for an integrated STEM curriculum is that PD programs can support teacher professional learning in integrated STEM when they are contextualised as action research projects with an academic partner. The case study presented in this chapter contributes to emerging evidence about what is successful. A longitudinal study would be useful for further understanding how to take integrated STEM education in elementary schools to where it needs to be.

References

Audit Office of New South Wales. (2019). *Supply of secondary teachers in STEM-related disciplines.* Sydney: NSW Auditor-General. Retrieved from https://www.audit.nsw.gov.au/publications/latest-reports/supply-of-secondary-teachers-in-stem-related-disciplines

Australian Academy of Sciences. (2018). *Primary Connections: Linking science with literacy*. Retrieved from https://primaryconnections.org.au

Beane, J. (1997). *Curriculum integration: Designing the core of a democratic school*. New York: Teachers College Press.

Berry, A. (2018). *STEM education: What does it mean for teachers?* 2018 Dean's lecture. Melbourne: Monash University. Retrieved from http://youtu.be/LbZlbG5bX68?a

Blackley, S., & Howell, J. (2015). A STEM narrative: 15 years in the making. *Australian Journal of Teacher Education*, *40*(7), 102-112. doi.org/10.14221/ajte.2015v40n7.8

Bonfiglio-Pavisich, N. (2018). Technology and pedagogy integration: A Model for meaningful technology integration. *Australian Educational Computing*, *33*(1). Retrieved from http://journal.acce.edu.au/index.php/AEC/article/view/165

Bybee, R. W. (2018). *STEM education: Now more than ever*. Arlington, VA: NSTA Press.

Campbell, A., & Groundwater-Smith, S. (Eds.). (2010). *Action research in education*. Los Angeles: Sage.

Chapman, S., & Vivian, R. (2017). *Engaging the future of STEM*. Sydney: Chief Executive Women Ltd. Retrieved from *https://cew.org.au/wp-content/uploads/2017/03/Engaging-the-future-of-STEM.pdf*

Department of Education and Training. (2018). *Optimising STEM industry–school partnerships: Inspiring Australia's next generation – Issues paper.* Retrieved from https://docs.education.gov.au/documents/optimising-stem-industry-school-partnerships-inspiring-australias-next-generation-issues

Education Council. (2015). *National STEM school education strategy 2016–2026*. Retrieved from http://www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/National%20STEM%20School%20Education%20Strategy.pdf

English, L.D. (2016). STEM education: K-12: Perspectives on integration *International Journal of STEM Education*, 3(3). doi.org/10.1186/s40594-016-0036-1

Glancy, A., Moore, T., Guzey, S., Mathis., Tank., & Siverling, E. (2014, June). Examination of integrated STEM curricula as a means towards quality K-12 engineering education. In *Proceedings of the 2014 American Society of Engineering Education Annual Conference and Exposition.* Indianapolis, IN. Retrieved from https://peer.asee.org/examination-of-integrated-stem-curricula-as-a-means-toward-quality-k-12-engineering-education-research-to-practice

Groundwater-Smith, S. (1988). Credential-bearing enquiry based courses: Paradox or new challenge? In J. Nias & S. Groundwater-Smith (Eds.), *The enquiring teacher: Supporting and sustaining teacher research*. Lewes: Falmer.

Groundwater-Smith, S. & Mockler, N. (Eds.). (2015). *Big fish, little fish: Teaching and learning in the middle years*. Melbourne: Cambridge University Press.

Grundy, S., & Kemmis, S. (1982). *Education action research in Australian schools: The state of the art.* Geelong: Deakin University Press.

Hobbs, L., Jakab, C., Millar, V., Prain, V., Redman, C., Speldewinde, C., Tyrtler. R., & van Driel, J. (2017). *Girls' Future–Our Future, The Invergowrie Foundation STEM Report*. Melbourne: Invergowrie Foundation. Retrieved from apo.org.au/system/files/117526/apo-nid117526-470536.pdf

Hunter, J. (2013). *Exploring technology integration in teachers' classrooms in NSW public schools.* Unpublished doctoral dissertation*.* Sydney: University of Western Sydney.

Hunter, J. (2015a). *Technology integration and High Possibility Classrooms: Building from TPACK.* New York: Routledge.

Hunter, J. (2015b). High Possibility Classrooms in the middle years: A model for reform. In S. Groundwater-Smith & N. Mockler (Eds.), *Big fish little fish: Teaching and learning in the middle years*. Cambridge: Cambridge University Press.

Hunter, J. (2017). Switching middle school teachers onto STEM using a pedagogical framework for technology integration: The case for High Possibility Classrooms in Australia. In L. Liu & D. D. Gibson (Eds.), Research highlights in technology and teacher education 2017 (pp. 37-46). Waynesville, NC: AACE.

Hunter, J. (2019). High Possibility Classrooms: A new model for technology integration. In Information Resources Management Association (Eds.), *TPACK: Breakthroughs in research and practice* (pp. 518-547). IGI Global. doi:10.4018/978-1-5225-7918-2.ch025

Hunter, J., & Mitchell, J. (2011). The insider and outsider model of professional learning. In N. Mockler & J. Sachs (Eds.), *Rethinking educational practice through reflexive inquiry* (pp. 183-196). New York: Springer.

Jefferson, M., & Anderson, M. (2017). Transforming schools: Creativity, critical reflection, communication, collaboration. Bloomsbury Publishing.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(11). doi.org/10.1186/s40594-016-0046-z

Kemmis, S. (2011). A self-reflective practitioner and a new definition of critical participatory action research. In N. Mockler & J. Sachs (Eds.), *Rethinking educational practice through reflexive inquiry* (pp. 11-29). Springer: Dordrecht.

Kemmis, S., & McTaggart, R. (1988). *The action research planner* (3rd ed). Geelong, VIC: Deakin University Press.

Kirkby, L. (2015). Leading teacher professional learning in the middle years. In S. Groundwater-Smith & N. Mockler (Eds), *Big fish, little fish: Teaching and learning in the middle years.* Port Melbourne: Cambridge University Press.
Koziol, M. (2018, April 21). STEM review: Schools and universities are sending the 'wrong signals' to students, chief scientist finds. *The Sydney Morning Herald*. Retrieved from https://www.smh.com.au/politics/federal/stem-review-schools-and-universities-are-sending-the-wrong-signals-to-students-chief-scientist-finds-20180420-p4zasn.html
Light, N. (2018, June 21). Industry leaders want education to focus on STEM to help fill 2.4M expected job vacancies. *The Dallas Morning News*. Retrieved from http://www.govtech.com/education/higher-ed/Industry-Leaders-Want-Education-to-Focus-on-STEM-to-Help-Fill-24M-Expected-Job-Vacancies.html
Lin, T. J., Lin, T. C., Potvin, P., & Tsai, C. C. (2018). Research trends in science education from 2013 to 2017: A systematic content analysis of publications in selected journals. *International Journal of Science Education*. doi.org/10.1080/09500693.2018.1550274
Littlejohn, C. (2016). Messy or not: The role of education institutions in leading successful applications of technology in teaching and learning. *Australian Education Leadership*, *38*(3), 62-65.
Little Scientists. (2019). Retrieved from https://littlescientists.org.au/
McGowan, M. (2018, 9 July). University funding could be tied to maths and science teaching push. *The Guardian* (Australian edition). Retrieved from https://www.theguardian.com/australia-news/2018/jul/09/university-funding-could-be-tied-to-maths-and-science-teaching-push
McWilliam, E. L. (2009). Teaching for creativity: From sage to guide to meddler. *Asia Pacific Journal of Education, 29*(3), 281-293. Retrieved from https://eprints.qut.edu.au/32389/1/c32389.pdf
Meier, D. (2002). *In schools we trust: Creating communities of learning in an era of testing and standardization*. Boston: Beacon.
Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A new framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054.
Mockler, N. (2018). Curriculum integration in the twenty-first century: Some reflections in light of the Australian Curriculum. *Curriculum Perspectives, 38*(2), 129-136. doi:10.1007/s41297-018-0047-9
Mockler, N., & Sachs, J. (Eds.). (2011). *Rethinking educational practice through reflexive inquiry*. Springer: Dordrecht.
Moomaw, S., & Davis, J. A. (2010). STEM comes to preschool. *Journal of the National Association for the Education of Young Children, 65*(5), 12-18.
Moore, T.J., Johnson, C., Peters-Burton, E.E., & Guzey, S.S. (2016). The need for a STEM road map. In Moore, T. J., Johnson, C. C., Peters-Burton, E. E., & Guzey, S. S. (Eds.), *STEM road map: A framework for integrated STEM education.* London, UK: Routledge.
Munns, G., Sawyer, W., & Cole, B. (2013). *Exemplary teachers of students in poverty.* Abingdon: Routledge.
Murdoch, K. (2015). *The power of inquiry*. Northcote: Seastar Education.
National Academy of Engineering and National Research Council. (2014). *STEM integration in K-12 Education: Status, prospects, and an agenda for research*. Washington, DC: The National Academies Press. doi.org/10.17226/18612
National and Innovation Science Agenda (NISA). (2015). *Welcome to the ideas boom.* Retrieved from https://www.industry.gov.au/sites/g/files/net3906/f/July%202018/document/pdf/national-innovation-and-science-agenda-report.pdf
National Assessment Governing Board. (2014). *2014 abridged technology and engineering literacy framework for the 2014 National Assessment of Educational Progress.* Retrieved from https://eric.ed.gov/?id=ED563941
National Research Council (NRC). (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. Washington D.C.: National Academies Press. Retrieved from https://www.nap.edu/resource/13398/dbasse_070895.pdf
Next Generation Science Standards. (nd). Retrieved from https://www.nextgenscience.org/
Niss M. (2015). Mathematical competencies and PISA. In K. Stacey & R. Turner (Eds.), *Assessing mathematical literacy*. Cham: Springer.
Organization for Economic Co-operation and Development (OECD). (2012). *Preparing teachers and developing school leaders for the 21st century: Lessons from the around the world*. Paris: OECD Publishing. Retrieved from https://www.oecd.org/site/eduistp2012/49850576.pdf
Prinsley, R., & Johnston, E. (2015). Transforming STEM teaching in Australian primary schools: Everybody's business. *Australian Government: Office of the Chief Scientist*. Retrieved from www.appa.asn.au/wp-content/uploads/2015/12/Transforming-STEM-teaching.pdf

Ringland, N., & Fuda, B. (2018, February 2). We have a national STEM strategy, but what we need is a successful one. *The Conversation*. Retrieved from https://theconversation.com/we-have-a-national-stem-strategy-but-what-we-need-is-a-successful-one-87088
Rosicka, C. (2016). *From concept to classroom: Translating STEM education research into practice*. Camberwell, VIC: ACER. Retrieved from https://research.acer.edu.au/cgi/viewcontent.cgi?article=1010&context=professional_dev
Shernoff, D. J. Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education, 4(*13). doi.org/10.1186/s40594-017-0068-1
Smith, A. (2018, 21 March). STEM has become a buzzword and a fad: NSW education minister. *The Sydney Morning Herald*. Retrieved from https://www.smh.com.au/politics/nsw/stem-has-become-a-buzzword-and-a-fad-nsw-education-minister-20180321-p4z5iw.html
Smits, A., Voogt, J., & van Velze, L. (2019). The development of technology integration in a graduate course for practicing teachers. In M. L. Niess & H. Gillow-Wiles (Eds.), *Handbook of research on TPACK in the digital age*. IGI Global.
Stake, R. E. (1998). Case studies. In N.K. Denzin & Y.S. Lincoln (Eds), *Strategies of qualitative inquiry* (pp. 86-109). Thousand Oaks, CA: Sage.
STEM Partnerships Forum. (2018). *Optimising STEM industry-school partnerships: Inspiring Australia's next generation*. Carlton South, VIC: Education Council. Retrieved from www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/Reports%20and%20publications/Publications/Optimising%20STEM%20Industry-School%20Partnerships%20-%20Final%20Report.pdf
Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education, 3*(1). doi.org/10.20897/ejsteme/85525
Timms, M., Moyle, K., Weldon, P., & Mitchell, P. (2018). *Challenges in STEM learning in Australian schools: Literature and policy review*. Camberwell, VIC: ACER. Retrieved from https://works.bepress.com/pru_mitchell/38/download/
Tytler, R., Osborne, J., Williams, G., Tytler, K., & Cripps Clark, J. (2008). *Opening up pathways: Engagement in STEM across the primary–secondary school transition*. Australian Department of Education, Employment and Workplace Relations. Retrieved from https://docs.education.gov.au/system/files/doc/other/openpathinscitechmathenginprimsecschtrans.pdf
Varadharajan, M. (2017, November 29). Want to solve our STEM skills problem? Bring in the professionals. *The Conversation*. Retrieved from https://theconversation.com/want-to-solve-our-stem-skills-problem-bring-in-the-professionals-87513
Wall, J. (2016). A science, technology, engineering and mathematics (STEM) review of the research. *Scan, 35*(2), 27-41. Retrieved from https://education.nsw.gov.au/teaching-and-learning/professional-learning/scan/media/documents/vol-35/Research-a-STEM-literature-review.pdf
Wiggins, G., & McTighe, J. (2007). *Schooling by design.* Alexandria, VA: ASCD.
Williams, J. (2011). STEM education: Proceed with caution. *Design and Technology Education: An International Journal*, *16*(1), 26-35.
Yoder, S., Bodary, S., & Johnson, C. C. (2016). Effective program characteristics, start-up and advocacy for STEM. In C.C. Johnson, E. E Peters-Burton and T. J. Moore (Eds.), *STEM road map: A framework for integrated STEM education* (pp. 211-237). New York: Routledge.
Zollman, A. (2012). Learning for STEM literacy: STEM literacy for learning. *School Science and Mathematics, 112*(1), 12-19. doi:10.1111/j.1949-8594.2012.00101.x