Switching middle school teachers onto STEM using a pedagogical framework for technology integration: The case for High Possibility Classrooms in Australia

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Abstract: Education in STEM (Science, Technology, Engineering and Mathematics) is a significant issue for governments and organizations across the world as concerns are expressed about students' lack of progress in these areas. In Australia, middle school teachers' capacity and confidence in teaching the STEM disciplines has been identified as wanting. The paper draws on findings from a study that used a pedagogical framework for technology enhanced learning to develop integrated STEM units of work. Analysis of the findings illustrates that the *High Possibility Classrooms* framework builds teacher agency in STEM and that being involved in professional development conducted, as a research experience is beneficial. The paper argues for greater teacher professional development resourcing in schools to make STEM an education priority, and it concludes by recommending that more middle school teachers consider pedagogical scaffolds to integrate curriculum and enhance their professional knowledge in STEM.

Introduction

According to recent reports by Australia's Office of the Chief Scientist (2013, 2014, 2015) there is an urgency to advance societal knowledge in Science, Technology, Engineering and Mathematics (STEM). Key to that call to action is the role of teachers in elementary, middle and high school classrooms. While references to Science tend to be more common in many STEM reports in both Australia and elsewhere, Engineering education is receiving less attention, especially with respect to elementary and middle school education (Hudson et al., 2015), and teachers will require targeted professional development to address that specific discipline (Finkel, 2016; Nadelson et al., 2012; Tytler et al. 2008; Tytler, 2016).

In the United States, the National Science Teachers Association (NSTA) appeals to schools to establish a STEM plan of action where the emphasis is on determining a clear purpose for STEM, having a school policy, setting out a program or strategy across the school year or for periods of three to five years, and then focusing on the practices/units of work to achieve improvements in STEM education (National Research Council, 2012). Bybee (2013) reminds us that "achieving significant levels of change in STEM education cannot be accomplished quickly" (p. 90). Here, questions arise: What does it actually mean to teach the STEM disciplines together? Is it transdisciplinary or interdisciplinary or multidisciplinary? How will we know if it has been achieved? What professional development will effectively support teachers at all levels of schooling? How do you increase teacher capacity and confidence in the STEM disciplines? And, in all of this, what is the place of STEAM with 'A' for the Arts as crucial to developing well-rounded citizens?

Such questions are critical and prompt us to recall that teachers' pedagogical and content knowledge (PCK) for STEM requires ongoing scrutiny to better inform the teaching of the STEM disciplines in schools and to understand the key role that technology integration plays in this (McCrory, 2008; Mishra & Koehler, 2006; Shulman, 1986). Teaching STEM as integrated curriculum is a relatively new field for middle school education in Australia, and educators look forward to considerable investment in STEM education research to stimulate and corroborate students' learning outcomes (Tytler et al., 2008). In the US, specialist STEM middle schools have a much longer history in school education (National Research Council, 2012).

This study of sixteen teachers in Australian middle schools drew on notions of teacher concerns of 'teacher-self efficacy, agency and leadership related to an innovation' (Costa & Garmston, 2006). The research was designed to build middle teachers' capacity and confidence in STEM using a new pedagogical framework known as *High Possibility Classrooms* (Hunter, 2015a, 2015b, 2015c; Belbase, 2016; Groundwater-Smith & Mockler, 2016; Lin et al., 2017; Reynolds, 2015) through the construction of integrated units of work. The community of principals who funded the research approached the author to conduct the study in their schools; they knew of the HPC framework and identified STEM as a priority in teacher professional development in the middle years.

Often in education literature, the terms professional development and professional learning are used interchangeably. In this paper the term *professional development* is the activity, process and experience teachers engage with in order to develop their *professional learning*. There appears to be some agreement that professional learning primarily should be school-based and school-managed, and be focused on improving and reflecting on teaching practice (Kemmis & Smith, 2008; Needham, 2011; Mockler & Sachs, 2011). The term *middle school teachers* in this paper refer to teachers who in Australian schools teach students in Years 5 to 8 (approximately 11 to 14 years old). In the paper *italics* are used for reader ease to give emphasis, to distinguish HPC conceptions and themes, and for verbatim teacher comments from the data.

Background literature

Pedagogical frameworks for teaching in schools with technology abound (Hunter, 2015a; Mishra & Koehler, 2006; Puentedura, 2006). The two most relevant to this paper are Hunter's (2015a) *High Possibility Classrooms* (HPC), and Mishra and Koehler's (2006) Technological Pedagogical Content Knowledge (TPACK), which framed the development of HPC.

HPC was established from research into exemplary teachers' knowledge of technology integration in classrooms in Australian schools. It was subsequently validated in further studies (Hunter, 2015b, 2015c; Groundwater-Smith & Mockler, 2016; Lin et al, 2017). The framework builds on the considerable scholarship of TPACK (Hunter, 2015a; Littlejohn, 2016; Mishra & Koehler, 2006; Reynolds, 2015). The HPC framework's five conceptions of *theory*, *creativity*, *public learning*, *life preparation* and *contextual accommodations* (see Figure 1) form an evidence-based scaffold that explains particular teachers' knowledge of technology integration in action. Each conception is underpinned by themes of pedagogical strategies and students' learning processes (see Table 1). For example, the first conception, *theory* refers to how the:

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

The other four HPC conceptions have also proved to be potent forces in teachers' knowledge of technology integration. The second conception is *creativity*, 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 and it enhances their learning outcomes. The fourth conception, *life preparation*, means technology is operationalised in the real world for students, giving them a voice, denoting ownership and responsibility, and engaging and motivating them. In the fifth conception, *contextual accommodations*, the exemplary teachers' knowledge is personal.

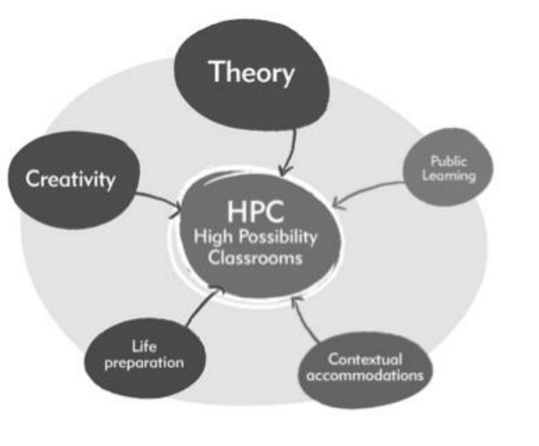

Figure 1. High Possibility Classrooms Framework featuring the five conceptions

Theory-driven technology practice	Creativity for learning through technology	Public learning through technology	Life preparation using technology	Contextual accommodations using technology
Technology drives construction of learning	Technology boosts creativity	Technology scaffolds performance	Technology operationalises 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 conversation and thinking				
Technology engages students in authentic ways				

Table 1. High Possibility Classrooms framework with 22 underpinning themes

Technology integration plays a critical role in supporting school teachers to take risks with approaches that afford students opportunities to learn in different ways and with pedagogical frameworks scaffold that process (Groff & Mouza, 2008). Conceptual frameworks like TPACK have taken scholarship of technology integration ahead. Thousands of studies using TPACK have led teachers, schools leaders, education systems and policy makers to explore technology integration in education settings (Graham, 2011; Harris & Hofer, 2014; Koh et al., 2015). For many experienced teachers, the development of TPACK reminds them that:

> Selecting, adapting, and designing learning acivities, projects, and units is review work but the awareness of how digital tools and nondigital tools can be used in the service of students' learning … encompasses new information … about the planning/instructional design process. (Harris, 2008, p. 266)

In another study of the use of technology in Science teaching, McCrory (2011) describes how the fundamental goal is to decide where technology can help the students learn or help teachers teach. Decisions that guide technology use are about identifying curriculum and topics within the curriculum for which it is useful, and whether the technology is integral to the topic being taught or when it is embedded in the topic. Neiss (2005), for example, argued the case of a teacher using pH probe technology – that it was not just a tool for data collection but part of the Science itself, and that you learn Science by *using scientific tools* and *learning about* what particular tools do.

In the teaching of STEM in Australian schools, many education leaders and teachers are still deciding whether it should be taught as discrete curriculum in and of itself or whether an integrated approach is preferable. A comprehensive review (Tytler et al., 2008) of the literature on the barriers and supports that young people encounter in pursuing studies in STEM disciplines, presented no detailed or quantifiable data on the impact of middle years interventions on student retention and choice. What is noted is that "closer alignment of school Science practice with middle years pedagogical principles would improve student engagement and would be an important direction to take in any reform agenda" (p. 64). The principles determined as central to teacher effectiveness were questioning, exploration, risk taking, and learner autonomy and pedagogy (Tytler, 2007; Tytler et al, 2008). With these principles in mind, the objectives of this research were to:

- address gaps in the literature regarding innovative inquiry-based examples of STEM teaching in action in contemporary classrooms in the middle school context
- identify and investigate how conceptions and themes in the HPC framework enable or hinder STEM teaching and learning and identify what optimises or constrains teacher professional learning in middle schools
- develop and test a scalable intervention for assisting middle school teachers to teach STEM as it is practiced, that is, in ways that engage younger students in STEM and tap into their innate curiosity and sense of wonder by more effectively linking STEM to classroom learning that has real-world orientations.

The main research question underpinning the study is:

> How can middle school teachers improve their capacity and confidence in teaching STEM disciplines through use of a particular pedagogical scaffold like HPC?

The three sub-questions underpinning the main research question are:

i) What are the innovative STEM strategies and processes that the teachers use?
ii) How does the HPC framework enable or hinder STEM teaching and learning?
iii) What optimizes or constrains teacher professional learning in STEM when teachers' use HPC?

The full findings of the study are not reported here because of page limit constraints.

Methods

Context of the study

The five schools in the study are located in the western suburbs of a major city in Australia. The community of schools has a network of active principals and there are significant numbers of refugee and 'new arrival' students. Technology resources in classrooms are limited and Wi-Fi access is often unreliable. A brief description of each pseudonymous school is given in Table 2.

School name	Size /no. of students	Features
1.Blackwood	224	57% of the students have language backgrounds other than English.
2.Pinder	686	96% of the enrolments come from language backgrounds other than English.
3.Pinder North	329	85% of the enrolments come from language backgrounds other than English.
4.Pinder West	685	More than 50 languages are spoken within the school.
5.Rochester	585	90% of the enrolments come from language backgrounds other than English.

Table 2. Schools in the study

Participants

Sixteen teachers in the study had teaching experience that ranged from early career to more than 30 years. They were asked by their school principals to participate in the research and ongoing participation was voluntary. The STEM unit of work each school's teaching team (of 2-4 teachers at each site) developed was different, but the team needed to integrate each of the STEM disciplines with at least two conceptions from the HPC framework. Tab. 3 details the focus at each school, including the conceptions.

School name	Name of HPC conception/s Week 3/4 Interview 1	Name of HPC conception/s Week 7/8 Interview 2	STEM unit of work taught by each team/title/source
1.Blackwood	Creativity Life preparation Public learning	Theory Creativity Life preparation Public learning	Great Barrier Reef 21st Century Learning (website)
2.Pinder	Creativity Public learning	Life preparation Public learning	How does your garden grow? (adapted from a Greenhouse unit work produced by a local board of education)
3.Pinder North	Theory Creativity Life preparation Public learning	Theory Creativity Life preparation Public learning Contextual accommodations	Microorganisms Primary Connections unit (produced by the Australian Academy of Science)
4.Pinder West	Life preparation Public learning	Life preparation Public learning	Earthquakes Primary Connections unit (as above)
5.Rochester	Theory Creativity Public learning	Theory Creativity Public learning Contextual accommodations	It's Electrifying Primary Connections unit (as above) with modifications because of the school's focus on PBL and SOLE learning

Table 3. School names and focus of the integrated STEM Units, including conceptions from the HPC framework

Research design

The research design for the study used a mixed methods approach involving qualitative and quantitative data collection. All data collection was carried out over one school term (10 weeks) and involved:

- a pre- and post-innovation survey (not reported here)
- a professional development workshop led by the author that outlined the HPC framework and original research examples (Hunter, 2013, 2015a) and discussed the Action Learning (AL) process the teachers would use to develop their STEM unit/s of work that would integrate at least two of the HPC conceptions; teachers moved through AL cycles of planning, acting, and reflecting with an ultimate goal of sustainable change (Kemmis & Smith, 2008)
- 32 teacher interviews (two interviews per teacher)

- 30 classroom observations (one classroom was job share) using an observation schedule for mapping teacher and student actions in terms of the HPC framework conceptions and themes
- interviews with the school principals (not reported here)
- five focus groups with students (N=40) (not reported here)
- document analysis of lesson plans, syllabus documents, field notes and units of work
- an online community set up by the author to circulate STEM professional development ideas; it included STEM-related readings, policy documents, relevant websites, access to templates for planning including inquiry and design challenges, displays of classroom activities and processes in classrooms, digital artefacts from both teacher and student created work
- a cross-case meeting in the final week of the term for school presentations and sharing of preliminary research findings.

The research was conducted as a project in the University of Technology Sydney Research Office: Approval no. PRO 967. It met ethical concerns through the NEAF Human Ethics Application Process: Approval no. ETH 16-0422. The study was also approved under the relevant Department of Education State Education Research Applications Process: Approval no. 2016182. All relevant information sheets and consent forms detailed in the ethics applications were distributed and collected at each site. Each school has a pseudonym and teachers cannot be identified.

Analysis

Data collected for the study was analysed in four stages:

1. Interview and focus group data were transcribed and member-checked with participants
2. All field notes, classroom observations and documents, and school policies were summarized
3. All the round 1 interviews were read without specific coding, the goal being to promote familiarity with the responses and to reduce or break the primary data down into more manageable chunks (Miles & Huberman, 1994). Emergent themes surfaced independently were then examined against the research question and sub-questions. Data from this step generated codes that were imported into *NVivo 11*. This step was followed consistently for the round 2 interview data. Analysis of data from classrooms observations, field notes, teacher documents and student focus groups were included in the process of triangulation; and
4. A cross-case meeting involving all teachers was held at the conclusion of the data collection period (Hunter, 2017). The goal of this session was to complete the second survey and for each school team to share their STEM units to deepen knowledge and add further understandings to the research aims.

Results

Findings of the research are reported against the main research question and sub-questions for the study. Excluded are data from interviews with principals, the students and the two survey instruments completed by teachers. The results address: how middle school teachers can improve their capacity and confidence in teaching STEM disciplines through use of the HPC framework, the innovative strategies and processes that were used, and what optimized and constrained teacher professional learning in STEM.

Improving teacher capacity and confidence in STEM using the HPC framework

In Table 3 it is noted that at each school the conceptions from the HPC framework that teachers focused on expanded beyond those initially committed to in Week 3/4 of the research period, and by Week 7/8 most teachers had included all of them. For example, at Interview 1 the HPC conceptions focused on frequently were: *public learning*, *creativity*, *life preparation*, *theory* and *contextual accommodations* in that order. Ideas for *public learning* through performance and presentation dominated: "*We are focusing on public learning so we have set up a blog for the whole stage"* (Interview 1, Teacher 5).

After more time using HPC there was durable recognition of how *creativity* was fostered through the making and production activities in STEM. This was cited as evidence of the process of learning, often involving play. For example, teachers encouraged and demonstrated the use of applications like iMovie, Puppet Pals, PowerPoint, Canva, Scratch, C++ and Google Classroom. Commonly a focus in all classrooms, *creativity* assisted differentiation of learning, and a few teachers mentioned being motivated to 'play alongside their students'. Interview 2 data revealed the *creativity* conception as central in classroom practices, followed by *public learning, theory, life preparation* and *contextual accommodations*. One teacher said:

> *We also looked at creativity and we have tried to boost their creativity and their knowledge. Plus, I loved the playful moments where the students could enjoy themselves, be creative but also produce something based on what they have learnt. I played too and I learned as well. I really like that conception and now I think about it all the time. I did a lot more.* (Interview 2, Teacher 7)

Innovative strategies, processes, optimizations and constraints of teacher professional learning

References to 'hands on learning' were dominant in the data analysis. Other key references were to the necessity to teach difficult Science concepts; the use of real data to solve problems; and the perceived signs of greater student engagement, teamwork, and the focus on design and making activities. These findings emerged in the context of articulated increases in teacher 'capacity and confidence' that were expressed as leadership and self-efficacy supported by classroom observations, interviews (Interview 2, Teachers' 1-16) and document analysis. Teachers took pedagogical risks and moved from decidedly teacher-centred pedagogies to the student-centred approaches that are more appropriate for STEM (Bybee, 2013; Tytler et al, 2008). The nature of STEM activities, and the 'messiness' involved in construction/making/hands on learning had forced changes in pedagogy. Active use of a pedagogical scaffold, in this instance, HPC aided a more deliberate focus on teaching strategies and students' learning processes in lesson planning and in teaching practices.

Optimizing and constraining teacher professional learning in STEM using HPC

Teachers wanted more examples of STEM in action with the HPC framework and an additional, longer, professional development (PD) workshop. Moreover, with the benefit of hindsight they wanted to meet in their teams prior to the start of the term to plan the STEM units, one saying they had needed to "*retro-fit units of work"*, and "*we would have liked an individual session face-to-face with* [author] *prior to starting the research*" (Interview 2, Teacher 12). A few wanted a "go to list" of technologies to use with STEM. Teachers believed being involved in research that focused on PD was an opportunity to renew practice and professional growth; for example: "*It made us accountable for why we are using technology. I had never heard of HPC and I thought it sounded hard but it's actually brilliant and it fits perfectly with STEM. It's given me an anchor*" (Interview 2, Teacher 10). It also facilitated opportunities to have "*fun and play a bit more in the classroom*" (Interview 2, teacher 14), to see contemporary examples of good technology enhanced learning (TEL) practice, and find out about HPC and begin to understand the framework's approach to enacting STEM pedagogy.

Furthermore, teachers liked seeing what other schools were doing in STEM; a typical comment was: "*I have been teaching for 14 years ... you become stale … this puts us in a new situation"* (Interview 2, Teacher 1). One school team spoke of HPC as a new approach to pedagogy, a type of "*freedom in classroom learning"*. This was problematic at another site as students expected all their teacher*s "to teach in this new way"*, one teacher explaining: "*Students are rebelling when they go back to normal classroom teaching … we had to speak to some of them"* (Interview 2, Teacher 7).

Limitations and implications

The study was conducted over one school term (10 weeks) and whether the 'pressure and support' of action research for professional learning *insitu* is sustained after the initial intervention will be known over time. Recent anecdotal reports from the schools suggest that changes in teacher pedagogy remain, enthusiasm for planning STEM is evident and linking targeted approaches to the STEM disciplines in terms of students learning outcomes are being pursued at some sites. Sustained enactment of pedagogical change to teaching practice and building teacher capacity over the longer term is a key challenge (Ertmer, 2017). Longitudinal work in HPC is planned in a series of studies commencing in 2017. As a fresh, and very new pedagogical scaffold for technology enhanced learning HPC is resonating with education systems in schools, teacher education in universities, school leaders and teachers (Groundwater-Smith & Mockler, 2016; Hewes, 2016; Littlejohn, 2016; Smits, et al, 2017).

Discussion and conclusion

The main improvements in capacity and confidence that the HPC framework offered to middle years teachers' STEM teaching and learning were through its support for pedagogical accountability, its effect on changing pedagogy, and its fit with project-based learning (PBL) and self-organizing learning environments (SOLE), both of which encourage students to become information seekers, risk takers and problem finders. For one middle school team, the PBL approach to teaching and learning already in place at their school had given them a head start. Teachers variously explained that their professional growth led to an increased sense of personal agency, their encouragement of other teachers to push past their knowledge limits, and a desire to be a future STEM mentor.

The study also challenged teachers to reflect on the changes they had made to their teaching and learning. Apart from the perennial issues of wanting more time to plan, increased resources and better Wi-Fi connections, the teachers' responses focused on professional identity, knowing how to effectively integrate STEM into teaching and learning, and modification of current programs. These findings fit with what we know about successful teacher professional learning (Furlong, 2011; Timperley, 2012; Netolicky, 2016).

With hindsight, it was a formidable challenge for the teachers to deeply understand STEM content in specific topics, integrate it across four disciplines, and simultaneously embed in it at least two conceptions from a new pedagogical framework. They involved themselves in understanding both the content they needed to focus on and the knowledge they lacked. Throughout the duration of the research, each team also engaged in personal up-skilling using collaborative processes, online communities and resources, professional reading and after-school meetings. Although outside the scope of what is reported here, the research also significantly impacted student engagement in STEM content in each classroom.

Teachers light intellectual fires in their students and it is for this reason that effective STEM teaching is important (Finkel, 2016; Knapp, 2003; Lewis et al., 2006). This study has demonstrated that the HPC framework is a robust scaffold that works at scale and fits with delivery of content in the STEM disciplines; it gives teachers a language to talk about their practice because it focuses on developing teacher agency and pedagogical flexibility. This allows teachers to tap into approaches to learning that are both current and future-focused, and to demonstrate professional pedagogical accountability that is not imposed from outside but driven from within one's own professional judgement (Netolicky, 2016; Wiggins & McTighe, 2007).

Teachers who had this experience through involvement in this STEM research project are being encouraged to share it with other teachers and to coach their own school communities so that they may sustain the momentum of their professional learning (Costa & Garmston, 2006; Groundwater-Smith & Mockler, 2016). Resourcing of STEM education in Australia is not yet at a high enough level to ensure that the impetus will be widespread. The renowned education thinker Lawrence Stenhouse (1975) once said that curriculum "gives grace to living". This is what the careful resourcing of STEM in schools should enable; the STEM disciplines are friends of curriculum and teacher professional learning, not enemies to be avoided.

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