Chapter 1

More than coding: Positioning STEM education in policy and practice

Angela Fitzgerald[1], Carole Haeusler[1], and Linda Pfeiffer[2]
[1] University of Southern Queensland
[2] Central Queensland University

Introduction

A key element significantly influencing this collection is that nearly all of the contributors are passionate primary science teacher educators. Individually and collectively, we strive in our institutions, across Australia and stretching into New Zealand, to equip future primary school teachers with the appropriate knowledge, skills and attributes to be both learners and teachers of science. In achieving our goals, however, we recognize the science education landscape is rapidly changing and morphing as the integration of STEM (Science, Technology, Engineering, Mathematics) into our education policies, systems and classrooms continues to grow in size and stature, both nationally and internationally. Therefore, in remaining contemporary and cutting-edge, science teacher educators have been required to grapple with what STEM education means to them and how science can be harnessed as a vehicle for meaningful and authentic STEM learning and teaching. This book is a result of navigating and negotiating these tensions.

As referred to through the title of this chapter, the development of coding knowledge and skills is a national Government priority in Australian schools. Coding is to be 'taught' across all the compulsory years of schooling from 2020, which in this context means from Foundation (students aged around 5 years) to Year 10 (students aged around 16 years). This form of technology alone, however, does not necessarily address the depth and breadth of learning and teaching that quality pedagogical approaches to STEM affords. STEM education is certainly much more than the integration of digital technologies into practice. In countering this narrow vision, this book intends to provide voice to the ways in which primary science teacher educators have undertaken innovative and contemporary research to better understand how to meaningfully and authentically embed STEM into existing classroom, and more broadly educational, practices using science as a starting point.

In providing a segue into this collection, this chapter sets the scene by firstly delving into what STEM is and its prominent position in Australian educational policy, in particular, before exploring how STEM education can be understood through the lens of science and articulated in practice. The chapters in the collection are largely positioned within the Australian educational context, therefore the policies and practices of this setting are foregrounded across the collection. Links are made to the New Zealand context, but not to the same depth or extent. This chapter concludes by sharing the thinking behind how this collection has been structured and provides brief insights into what each chapter covers. These insights draw on national and international trends to provide a framing for the diverse array of chapters that were designed to push thinking about the possibilities inherent in wholeheartedly engaging with STEM learning and teaching in primary education contexts.

Navigating the STEM education landscape

STEM education is everybody's business. In order to prosper as a society, STEM education needs to be a focus for all stakeholders and at all levels. From the early years right through to senior high school, STEM education and its principles need to be embedded in everyday life and across the wider community. STEM experiences need to involve the appropriate skill development and understandings of the scientific process for teachers, schools, industry, parents and the wider community, who make up society and are the influencers of children, who hold the future in their hands. Inquiry approaches and STEM project opportunities for everyone are essential for improving future STEM educational outcomes for all.

Linda, chapter author

The acronym of STEM was itself coined by the National Science Foundation (NSF) in the United States in the mid-1990s (Jolly, 2017). In the following two decades, however, there has been a lack of clarity around the definition, which has caused confusion and uncertainty. The result being that STEM has been used to describe anything related to any one or combination of the four discipline areas: science, technology, engineering, and mathematics (Jolly, 2017). Among educators, some agreement has emerged around a common understanding of the interdisciplinary nature of the construct of STEM and what it can achieve. The following quotes are illustrative of this.

STEM education is an interdisciplinary approach to learning that removes the traditional barriers separating the four disciplines of science, technology, engineering, and mathematics and integrates them into real-world, rigorous, and relevant learning experiences for students (Vasquez, Sneider & Comer, 2013, p.4).

STEM education involves solving real-world challenges by establishing relationships between the four disciplines with the objective of expanding people's abilities by supporting technical and scientific education with a strong emphasis on critical and creative-thinking skills (Siekmann & Korbel, 2016, p.8).

While a critical component of STEM education is an interdisciplinary approach, the importance of a solid grounding in the individual disciplines should not be underestimated. As Alan Finkel, Australia's Chief Scientist, eloquently expressed, "a musician must master the instrument before they can master playing in an orchestra…. Students, focus on your discipline then you'll see your options expand" (Finkel, 2018, p.4). In the context of this book, an interpretation of these definitions and quotes might be that the development of conceptual knowledge and skills remain of key importance to classroom practice alongside the integration of STEM-focused activities and projects. This is equally true for both students and their teachers.

STEM and its prominence in education cannot be fully understood without first acknowledging the global trends in science and mathematics. These trends can be best recognised and represented through the lens of international testing. Two large-scale and widely cited international tests have been conducted since the 1990s that provide a baseline for student performance: the *Programme for International Student Assessment* (PISA) and the *Trends in International Mathematics and Science Study* (TIMSS). While it is beyond the scope of this chapter to provide an examination or critique of these assessment processes, a broad-brush comment would be that PISA and TIMSS have boosted the profile of science and mathematics education worldwide leading to increased scrutiny and subsequent funding. This has particularly been the case as decreasing performances in science and mathematics across the board have refocused global educational priorities. A key response being the rise in a STEM agenda as driven by politicians and policy makers as a way to improve the scientific and mathematical knowledge and skills, and ultimately test scores, of students and their teachers.

In the context of the Australian STEM landscape, two key policy documents are having a significant influence of STEM education and the direction it should take.

1. The *National STEM School Education Strategy* (Education Council, 2015) provides an overarching framework to unpack the interconnected nature of how Education and Industry are operating in each state/territory jurisdiction; and
2. The *Advancing Education: An action plan for education in Queensland* (Department of Education & Training, 2016) clearly articulates the importance of utilising partnerships and networks to align with national STEM goals.

Alongside this, in the primary schooling context, the Office of the Chief Scientist (OCS) released a position paper at the end of 2015 - *Transforming STEM teaching in Australian primary schools: Everybody's business* - that also has a key role to play in how STEM education is being positioned in this country. The paper (Prinsley & Johnston, 2015) proposed the following three steps of action to raise the profile and quality of STEM education in Australian primary schools:

1. Raise the prestige and preparedness of teachers through attracting high achievers and boosting rigour in pre-service education;
2. Transform STEM education through specialist teachers, national professional development, and supporting principals to be STEM leaders; and
3. Think bold, collaborate and lead change.

Three years on from the OCS report, there is a focus across the country to moving towards STEM specialist teachers in primary schools, which is being supported through education departments employing *STEM champions* to provide targeted professional development and relevant connections. Interestingly, while this has resulted in a greater emphasis on STEM in primary schools, many in reality are implementing technology and coding under the misguided understanding that this meets the STEM agenda.

In New Zealand, while STEM education is certainly part of the national conversation (e.g. Buntting, Jones, McKinley, & Gan, 2018), it has not dominated policy and practice to the same extent as it has in Australia. The general focus is, however, quite similar in terms of being economically-orientated towards the potential of STEM professions in enhancing the workforce and how best to equip students with the skills and knowledge they will require from the STEM disciplines.

Framing STEM education through the lens of science

> *Primary aged children are inherently interested in science and understanding how the world works. They also live in a world with serious environmental and technological challenges that rely on solutions dependent on interdisciplinary and transdisciplinary*

thinking. The big ideas of science are both interdisciplinary and transdisciplinary and thus provide a conceptual basis for STEM initiatives in education and beyond. By choosing real world scenarios and challenges as teaching contexts, STEM education is an exciting way of enhancing children's natural curiosity in science and showing them the relevance of science to their future.

Carole, chapter author

As STEM builds a steady presence in classrooms across Australia and New Zealand, debate over what constitutes *quality* STEM education is becoming more prominent (Bybee, 2013; English, 2017; Honey, Pearson, & Schweingruber, 2014). STEM education is generally accepted as requiring an integrated approach to curriculum development and implementation, so that it reflects the interdisciplinary approach required to address the complex technological, health and environmental and demands of the 21st century,

Nadelson and Seifert (2017) categorise the existing approaches to STEM education on a spectrum. One end of the spectrum is the traditional segregated teaching of STEM disciplines (e.g. traditional physics, mathematics, technology) and the other is a fully integrated approach to STEM where there is a seamless amalgamation of content and concepts from multiple disciplines similar to that applied in professional interdisciplinary teams (e.g. climate, environmental management, agriculture). In between, lies a mixed approach where the concepts of STEM disciplines are applied within problem-solving contexts. An example of how STEM concepts are applied is a Grade 6 problem-solving project on the design and construction of a building that with withstand earthquakes that involves all four STEM disciplines (English, King, & Smeed, 2017).

In terms of STEM education in practice, Bryan and colleagues (2015) as well as English (2017) do not advocate total content integration because they believe that students' learning of core disciplinary concepts and process may be compromised. To allay these concerns and avoid poorly constructed STEM curricula, these researchers advocate that teachers should be both *intentional* and *specific* when selecting the context and content for STEM learning and teaching. An example of this approach is documented in the work of King and English (2016) where they provide evidence of success with a STEM-oriented activity that applies the concepts of light in science and measurement in mathematics to build an optical instrument.

In support of efficacious STEM curricula, Chalmers, Carter, Cooper and Nason (2017) advocate that a 'big ideas' approach to STEM learning and teaching will facilitate students' construction of in-depth STEM knowledge. STEM big ideas are those which link together to form a coherent whole. There are three types:

1. Within-discipline big ideas that have application in other STEM disciplines (e.g. energy, scale);
2. Cross-disciplinary big ideas (e.g. patterns, models); and
3. Encompassing big ideas (e.g. conservation, relationships).

A big ideas approach views STEM learning as progressing towards an understanding of key ideas rather than a silo approach where individual STEM disciplines are viewed as bodies of knowledge. Science is ideally situated for this approach to STEM as the 'big ideas' of science

(Harlen, 2010; 2011) have application in other STEM disciplines (e.g. force and motion, atomic theory, energy), and are cross-disciplinary (e.g. reasoning and argument, hypothesis testing) and encompassing (e.g. systems, relationships, change). Therefore, considering STEM from the perspective of science will provide an integrative framework and allow students the opportunity to build in-depth STEM knowledge.

With this perspective in mind, this collection has chosen to use the lens of science education as an entry point into exploring advances in and contemporary approaches to STEM education in primary school settings. This focus not only enables a common thread to run through the chapters, but provides a fundamental conceptual framework for contextualising the integration of STEM into the school curriculum.

STEM education in practice

> *For me, the introduction of STEM to the classroom provides opportunities to contextualise learning in two key ways. Firstly, STEM-focused activities and projects replicate the ways in which professionals work - drawing on a wide range of skills and knowledge to enact change. Secondly, STEM provides a vehicle for meaningfully developing a range of important life and learning skills, such as working productively in a team and solving problems.*
>
> Ange, chapter author

In considering the possibilities inherent in STEM education, it is hard to ignore the global presence of STEM and its influence on the ways in which we understand and practice science education. Regardless of how you define this interdisciplinary construct, the growing focus on STEM professions and the future-oriented role of STEM in the workforce is becoming ever sharper and more prominent. To illustrate this, consider the following insights from the United States:

- By the end of 2018, there will have been more than 1.2 million job openings in STEM-related occupations (Fayer, Lacey, & Watson, 2017);
- Only 16% of Bachelor degrees obtained by 2020 will specialize in STEM-focused disciplines (Vilorio, 2014); and
- Within the next decade, 80% of jobs will require technology skills and expertise (Massachusetts STEM Advisory Council, 2010).

These statements become even more sobering for educators when considered in light of this quote from Alexis Ringwald, co-founder and CEO of LearnUp, “65% of today’s kids will end up doing job that haven’t even been invented yet” (Ringwald, 2015, p.1). The alignment of the above-mentioned knowns with this unknown is providing the impetus for STEM to have a presence in basic education. This is at odds, however, with what is happening at the chalk face in schools. STEM, as an integrated whole, is not an acknowledged component of the prescribed curriculum in many parts of the world. Regardless, there is a global policy push for space to be found to accommodate and integrate STEM learning and teaching into classroom activities (Howes, Kaneva, Swanson, & Williams, 2014). The reality of this imperative is that school-based engagement with STEM capabilities and competencies is typically becoming the responsibility of science teachers (or generalist classroom teachers, the approach used in primary education) (Rosicka, 2016). This leaves science teachers with the responsibility of ensuring that STEM education is enacted in meaningful and authentic ways to equip students with the skills, knowledge and attributes that will be valued and needed to be productive contributors in a STEM-focused future.

With the context in mind and an understanding of the kinds of challenges teachers, particularly those working in the sciences, face in preparing their students for an uncertain future, it is worth turning our thoughts to what this might mean for learning. Projecting into the future for both the science and STEM disciplines, it is recognized that a particular set of skills, knowledge and attributes will be required to experience success and be an effective contributor in the workplace as well as in the community at large (Siekmann & Korbel, 2016). With the rise of automation, this success will no longer necessarily be about manual and routine tasks. Instead the focus is shifting to higher-level skills that go way above and beyond what can be achieved through robotics and production lines. These so-called 21st century (21C) learning skills are fast becoming the focus driving the purpose of education worldwide, which signals a move away from the learning of information to the learning of what to do with and how to apply this information meaningfully (OECD, 2018).

It is important to note at this point the construct of 21C learning skills is not without its critics (Lamb, Maire, & Doecke, 2018). Some questions that are raised, for example, include 'Aren't we in the 21st century now?' and 'What are the skills that are actually needed for beyond this time and into the future?'. This chapter does not intend to engage with this particular argument per se, but would like to maintain the focus on what this approach means for learning more broadly. It is a push beyond learning as the attainment of facts, to concentrating on moving thinking to deeper levels and bringing to the fore the complexities inherent in knowledge and knowledge sharing, which has to a positive outcome from the introduction of STEM into the education sphere.

Outline of the book

In considering the ways in which the contributors to this collection are challenging the approaches and practices underpinning STEM education, four key themes were identified: (i) pedagogy, (ii) partnerships, (iii) professional development, and (iv) possibilities. We would like to articulate, however, that these identified themes should be interpreted as interconnected rather than existing in clearly delineated categories. Each of the 10 chapters have been grouped into one of the four sections depending on which theme it best represents, but we recognise that all of the chapters have some connections with the themes.

Theme 1: Pedagogy - Engaging learners in STEM through innovative practices

Theme 1 opens with *Kimberley Wilson's* introduction and exploration of a framework encompassing five key dimensions to engage diverse students in STEM, specifically low SES communities: (i) relevance, (ii) place and community, (iii) experience, (iv) creativity and problem-solving, and (v) transfer. The findings of the studies reported in *Chapter 2* indicate that the key to engaging diverse young people in STEM is innovative pedagogical practice that demonstrates responsiveness to the needs of individual young people and their communities. Ideally, this requires a school culture that supports and encourages innovation and experimentation.

Chapter 3 moves to a pedagogical approach adopted in primary school contexts: inquiry-based learning and teaching. Through their research, *Amanda Woods-McConney, Andrew McConney and Keryn Sturrock* describe the evolution of an inquiry-based activity in STEM - *Ball of Fear* - that was developed and used in a primary classroom setting. This activity was then further developed as an inquiry-based activity in a first-year university context for pre-service teachers enrolled in a content-focused science unit. The description of how this inquiry-based activity evolved provides a concrete example of what is meant by inquiry-based teaching and learning as well as highlights effective strategies and potential pitfalls of using this instructional approach in primary STEM.

This theme is rounded out by a chapter using a different set of lens from the others in this collection, namely early years education and mathematics. In offering this different point of view to STEM education and how it is enacted in the primary context, *Paula Mildenhall and Barbara Sherriff* present a case study from Western Australia describing how play-based approaches can be adopted in early years classrooms in the teaching of a STEM unit to promote specific discipline concept development. *Chapter 4* details how an early years teacher created an environment where the children were able to actively engage in STEM learning, specifically mathematical spatial reasoning skills, including the use of locational and directional language and the conceptual understanding of mass.

Theme 2: Partnerships – Working alongside schools, STEM professionals, and industry

This section consists of three chapters focused on productive STEM partnerships. This theme is first explored through a case presented by *Linda Pfeiffer and Kathryn Tabone*, which explores the key factors essential to successful partnerships based on the development and implementation of the Australia Pacific LNG STEM Central facility in regional Queensland. *Chapter 5* explores leadership, shared vision, and having the capacity to deliver good quality outcomes as critical components of a successful partnership between the education sector and industry to address STEM education and engagement at a local level.

Next, *Dayle Anderson and her colleagues* explore the potential and role of online citizen science (OCS) projects in enhancing and informing students' capabilities in relation to becoming curious and questioning citizens. In collaboration with four classroom teachers, *Chapter 6* draws on a range of evidence to highlight the various ways in which OCS projects, by engaging students in real science experiences, provide rich opportunities for integrated STEM learning and teaching.

Finally, *Kimberley Pressick-Kilborn and Anne Prescott* examine the conditions afforded to innovative STEM learning and teaching opportunities through the formation of productive partnerships between schools and universities. Through focusing on two key school-based events, *Chapter 7* looks at the impact of these STEM-focused experiences on a range of capabilities and competencies of the four key stakeholders: primary school students, in-service teachers, pre-service teachers, and teacher educators.

Theme 3: Professional development – Supporting teachers in STEM education

The third section of the collection explores professional development beginning with *Chapter 8.* Through their work, *Kathy Smith, Sindu George and Jennifer Mansfield* consider how culture influences primary teachers' understanding STEM education. In a study of primary school teachers in Australia and India, they found that differences in societal expectations, curriculum demands and testing regimes were all factors influencing how teachers in the two contexts interpret and enact STEM in the classroom and in turn their professional development needs.

This is followed by *Coral Campbell, Linda Hobbs and Lihua Xu's* collaboration that illustrates how a Maker Faire can facilitate the engagement of primary teachers and their students in STEM. *Chapter 9* explores the outcomes of a professional development program on STEM and entrepreneurship in which teachers and their students worked together to develop and showcase their own STEM projects and activities at this culminating event.

Theme 4: Possibilities – Looking for STEM outside the classroom walls

The final section of the collection further pushes the boundaries of what is possible in STEM education, starting with challenge to readers from *Kathy Paige, Lisa O'Keefe and David Lloyd* to think about STEM as being more than the sum of its parts and much more than a pipeline to future employment opportunities. By using a transdisciplinary lens, *Chapter 10* unpacks two examples of STEM education that draw upon pedagogies intended to empower students as knowledgeable citizens and ultimately position them to become activists for issues in their local communities

Rounding out the collection, *Angela Fitzgerald, Tania Leach, Kate Davis, Neil Martin, and Shelley Dunlop* discuss the ways in which informal spaces for STEM learning (STEM clubs) support STEM learning and teaching. In *Chapter 11,* three different STEM club contexts are represented – private provider, school-based, and library- based – as case studies that detail what STEM clubs are and what purposes they intend to achieve.

Through this collection, we are intending to inject some fresh evidence-based thinking into the STEM education conversation. By showcasing research being undertaken by predominantly science-focused primary teacher educators in Australia and New Zealand, we are showcasing the possibilities inherent in STEM education in the classroom and different ways of thinking about what is possible to enhance learning and teaching in this space. Whether you engage with this work by moving from cover to cover or you choose to dip in and out of chapters, we hope that these works cause you pause for thought and provide spark for future action.

References

Bryan, L. A., Moore, T. J., Johnson, C. C., & Roehrig, G. H. (2015). Integrated STEM education. In C.C. Johnson, E.E. Peters-Burton, & T.J. Moore (Eds.), *STEM road map: A framework for integration* (pp. 23-37). London: UK: Taylor & Francis.

Buntting, C., Jones, A., McKinley, L., & Gan, M. (2018). *STEM initiatives and issues in New Zealand.* Melbourne, Vic.: Australian Council of Learned Academies.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. Arlington, VA: National Science Teachers Association press.

Chalmers, C., Carter, M. L., Cooper, T., & Nason, R. (2017). Implementing "big ideas" to advance the teaching and learning of science, technology, engineering, and mathematics (STEM). *International Journal of Science and Mathematics Education*, *15*(1), 25-43.

Department of Education & Training. (2016). *Advancing education: An action plan for education in Queensland.* Retrieved from https://advancingeducation.qld.gov.au/ourplan/documents/advancing-education-action-plan.pdf

Education Council. (2015). *National STEM school education strategy: A comprehensive for science, technology, engineering and mathematics education in Australia.* Retrieved from http://www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/National%20STEM%20School%20Education%20Strategy.pdf

English, L. D. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education*, *15*(1), 5-24.

English, L. D., King, D., & Smeed, J. (2017). Advancing integrated STEM learning through engineering design: Sixth-grade students' design and construction of earthquake resistant buildings. *The Journal of Educational Research*, *110*(3), 255-271.

Fayer, S., Lacey, A., & Watson, A. (2017). *STEM occupations: Past, present, and future.* Washington, DC: U.S. Bureau of Labor Statistics.

Finkel, A., (2018). *The winning 2030 CV*. Retrieved from https://www.chiefscientist.gov.au/wp-content/uploads/STEM-in-Education-Conference-speech.pdf

Harlen, W. (2010). *Principles and big ideas of science education*. Retrieved from http://www.ase.org.uk/documents/principles-and-big-ideas-of-science-education/

Harlen, W. (2011). Working towards big ideas of science education. *Education in science*, 242, 20.

Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research* (Vol. 500). Washington, DC: National Academies Press.

Howes, A., Kaneva, D., Swanson, D., & Williams, J. (2014). *Re-envisioning STEM education: Curriculum, assessment and integrated, interdisciplinary studies.* London, UK: The Royal Society.

Jolly, A. (2017). *STEM by design: Strategies and activities for Grades 4-8.* New York, NY: Taylor & Francis.

King, D., & English, L. (2016). Designing an optical instrument: A culminating STEM activity for a primary science light unit. *Teaching Science*, *62*(4), 15-24.

Lamb, S., Maire, Q., & Doecke, E. (2018). *Key skills for the 21st century: An evidence-based review.* Sydney, NSW: Department of Education.

Massachusetts STEM Advisory Council. (2010). *A foundation for the future: Massachusetts' plan for excellence in STEM education.* Retrieved from http://www.mass.edu/stem/documents/MA_STEM_Plan_Final_9_28_10.pdf

Nadelson, L. S., & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *The Journal of Educational Research*, *110*(3), 221-223.

OECD. (2018). *The future of education and skills: Education 2030.* Paris, France: Organisation of Economic Cooperation and Development.

Prinsley, R., & Johnston, E. (2015). *Transforming STEM teaching in Australian primary schools: Everybody's business.* Canberra, ACT: Office of the Chief Scientist.

Ringwald, A. (2015). *3 ways to fix our broken training system: World Economic Forum report*. Retrieved from https://www.weforum.org/agenda/2015/01/three-ways-to-fix-our-broken-training-system/

Rosicka, C. (2016). *From concept to classroom: Translating STEM education research into practice.* Melbourne, Vic.: Australian Council for Educational Research.

Siekmann, G., & Korbel, P. (2016). *Defining 'STEM' skills: review and synthesis of the literature — support document 1*. Adelaide, S.A.: NCVER.

Vasquez, J.A., Sneider, C., & Comer, M. (2013). *STEM lesson essentials, Grade 3-8: Integrating science, technology, engineering, and mathematics.* New York, NY: Heinemann.

Vilorio, D. (2014). STEM 101: Intro to tomorrow's jobs. *Occupational Outlook Quarterly, (Spring)*, 1-12.