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STEM Education Across the Learning Continuum

Early Childhood to Senior Secondary

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Foreword

STEM education has received substantial, global attention in recent times with educators, policy-makers, and researchers calling for improvements in students' achievements and engagement. Indeed, the need for STEM education across the school continuum has never been greater, nor have the challenges. Education systems cannot standstill. The impact of global disruption is increasing exponentially; our students need the skills to both manage and advance technological developments. It is thus not surprising that we have seen an upsurge in books and journals devoted to STEM education and research, all contributing to the many perspectives (and controversies) on designing, implementing, and assessing students' learning in STEM. Issues receiving most debate appear to be whether the STEM disciplines should be integrated and to what extent, approaches to integration, and whether the disciplines receive equitable attention within integrated programmes (e.g. Bybee, 2013; English, 2017; Honey, Pearson, & Schweingruber, 2014).

Against this backdrop of debates, *STEM Education Across the Learning Continuum: Early Childhood to Senior Secondary*, presents fresh perspectives on issues that have received comparatively little attention. Robyn Jorgensen's chapter (Chap. 9) on STEM leaders in remote indigenous communities is a case in point. The challenges that Jorgensen highlights in her chapter would apply to many such communities, where equipping beginning teachers with the "pedagogical capital" to facilitate and lead STEM-based learning is paramount.

Comprehensive STEM frameworks that span the learning spectrum are not prolific in the literature so I was particularly pleased to see the conceptual *Sustaining STEM* framework by Murphy, MacDonald, and Danaia (Chap. 2). As these authors highlight, none of the existing frameworks adequately addresses all aspects of STEM including cognitive, affective, and equity factors, among others. Establishing effective STEM learning environments is invariably a challenge, especially in secondary schools. The authors provide valuable suggestions here, as do other chapters in the book, such as Danaia and Murphy's novel approach involving pedagogical partnerships in primary and secondary STEM education.

Integrating STEM experiences is challenging in itself, but is made more so when there are misalignments between disciplinary contents. I found this aspect particularly enlightening in Larkin and Miller's chapter, where they identify conflicts between digital technologies and numeracy in the Australian Curriculum. This is especially noticeable in integrated projects when students advance beyond their curriculum level in one STEM discipline, such as technology, but have not learned required content in another discipline, such as mathematics. On the other hand, my own research on mathematical modelling in interdisciplinary contexts has revealed how students can generate important mathematical ideas beyond their grade level (e.g. English, 2009). Students' capabilities in extending their own learning in open-ended modelling problems suggest that they could do likewise in an integrated mathematics and technology activity, depending on the content needed.

Thornton's report on "threshold concepts" in primary school mathematics and science (Chap. 13) is another chapter that is especially informative in developing integrated STEM programmes. As Thornton explains, the use of "big ideas" and threshold concepts across the STEM disciplines can serve as powerful integrators in STEM-based projects. Threshold concepts (e.g. limit, atomic structure) extend beyond big ideas in that they not only serve to link the disciplines but also transform one's thinking, such as a shift in understanding a discipline, a shift in values, or indeed a change in the way one perceives the world. In analysing Australian curriculum resources in mathematics and science, Thornton identifies both big ideas and threshold concepts that educators will find insightful in planning integrative learning experiences. Although Thornton touches upon statistical big ideas, there are many more core statistical concepts and processes that are applied to both mathematics and science investigations. Greater awareness needs to be made of the important role statistics plays across the STEM disciplines.

As I have indicated, the diversity of the chapters adds to the book's appeal and relevance to STEM practice. The chapter by Liz Dunphy on picture book pedagogy is another case in point. In contrast to chapters that explore the applications of technology (e.g. Munday, Thompson, and McGirr, Chap. 7), Dunphy examines a teaching tool, namely, picture books, which have existed long before technology as we know it came into being. We often don't take advantage of the learning affordances in the immediate environment. Picture books can be a powerful means of facilitating young children's mathematics learning—it is simply a matter of looking for the opportunities and knowing how to make maximum use of them. Surprisingly, as Dunphy notes, many educators do not use picture books in their teaching, or at least sparingly, despite their key role in supporting STEM learning. Knowing what to look for in picture books to support this learning, however, can be rather difficult especially for beginning teachers, as Dunphy indicates. To assist educators in the selection and use of picture books, Dunphy provides a helpful framework that considers how content is presented, the key ideas and processes explored, and opportunities for children's participation. Picture books can foster learning not only in mathematics but also across all of the STEM disciplines including early engineering (English, 2018). Picture books can be used in two fundamental ways—general picture books that do not specifically target a particular

STEM domain but can serve as a rich springboard for STEM learning experiences, and books that directly target one of the STEM disciplines (e.g. Burns, 2008). Many such books exist for early mathematics learning, as Dunphy points out.

The importance of affect and engagement in STEM education applies to all learning but especially in mathematics and science, where enthusiasm for the disciplines often wanes as students progress up the primary grades. The senior secondary years exhibit a further decline in interest in the STEM fields, as Attard, Grootenboer, Attard, and Laird (Chap. 11) indicate in their chapter. They address key facets of the affective domain, namely, beliefs, values, attitudes, and feelings, all of which are complex and not easy to change if students' prior experiences in one or more of the STEM disciplines have been negative. Attard et al. highlight important issues for policy-makers to consider as new STEM programmes are developed. One approach that I have found productive in fostering engagement in and enjoyment of STEM is linking a discipline to students' community. For example, exploring the roles of engineers in improving students' local communities and involving engineers in students' projects can enhance interest and motivation in STEM.

Although I have not touched on every chapter, the entire book presents valuable perspectives—both practical and theoretical—that enrich the current STEM agenda. As such, the book makes a substantial contribution to the literature and could very well serve as a basis for future research and publications.

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Chapter 1
Introduction

Amy MacDonald, Lena Danaia and Steve Murphy

Abstract This edited book brings together a collection of work from around the world in order to consider effective STEM education from a range of perspectives. This opening chapter outlines the key challenges in research, policy and practice for STEM education, from early childhood through to senior secondary education. The chapter describes the context for the development of the book, including the political and educational imperatives that underpin current approaches to STEM education around the world. Finally, it introduces the content of the chapters within the volume, noting the range, breadth and implications of various positions described by the chapter authors.

1.1 Introduction

STEM education engages learners in the exploration of real-world problems and contexts, drawing on the capabilities of Science, Technology, Engineering and Mathematics disciplines (Gee & Wong, 2012). As such, STEM education is not the simple integration of these component disciplines, but an authentic and engaging approach to equipping learners with the skills to manage dynamic knowledge and complex, authentic scenarios. Through STEM education, learners not only develop the knowledge and skills associated with the component disciplines, they also develop competencies and dispositions that will enable them to pursue STEM careers

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and become active citizens in a rapidly evolving and technology-dominated world (Capraro & Slough, 2013; Zollman, 2012). Jurisdictions across the world have dedicated significant funds and effort to implementing STEM education strategies (for example, Education Council, 2015; Gough, 2015; Morgan & Kirby, 2016; National Science and Technology Council, 2013; UNESCO, 2015) that call for educators and educational researchers to deliver improved STEM education programmes.

Internationally, the STEM education movement has been set a wide-ranging mission, aiming to impact on learners from all ages and from disparate social and cultural backgrounds. There is strong evidence that STEM education needs to begin in early childhood, with early competencies shown to be predictive of later achievement (Johnston, 2011; Watts, Duncan, Siegler, & Davis-Kean, 2014). Further, the literature challenges STEM educators to address key educational transitions to maintain students' engagement with STEM learning (Perry, MacDonald, & Gervasoni, 2015; Tytler, Osbourne, Williams, Tytler, & Cripps Clark, 2008). There are also significant equity issues to be addressed through STEM education. Girls feel less positive about STEM and are far less likely to pursue further STEM studies or careers (Marginson, Tytler, Freeman, & Roberts, 2013). Students from particular cultures, from low socioeconomic backgrounds or from non-metropolitan areas all achieve more poorly in STEM (Thomson, De Bortoli, & Underwood, 2017). This broad brief combined with some ambiguity about best practice means STEM education is an incredibly complex space for educators and educational researchers alike.

This edited book represents a comprehensive view of effective STEM education that spans early childhood to senior secondary education. The chapters in this book theorise effective STEM education in relation to one or more of the following interacting aspects:

1. Knowledge: The *nature* of STEM knowing and knowledge (for example, accessing STEM knowledge, dealing with uncertainty), rather than *what* should be known;
2. Skills: Transdisciplinary skills, beyond those of the individual disciplines (for example, problem-solving, creativity, critical thinking); and
3. Engagement: The affective domain of STEM education (for example, academic emotions, motivation).

Additionally, the book addresses critical issues in STEM education, including transitions and trajectories, gender, rurality, socioeconomic status and cultural diversity. To the best of the editors' knowledge, this is the first edited research book to consider STEM education from early childhood through to senior secondary. Along with the diversity among the author team, this makes this volume quite significant in its breadth and in its potential influence on the field.

1.2 The STEM Agenda

For at least the last decade, many governments around the world have been in pursuit of a STEM skilled workforce and a STEM literate citizenry (Gough, 2015), and STEM education has been positioned as the key strategy for achieving these goals. STEM education is seen as a vehicle for improving a nation's global competitiveness and ensuring its economic future (Breiner, Harkness, Johnson, & Koehler, 2012). Fensham (2008), in his report to UNESCO, argued that socially and environmentally sustainable development requires a supply of scientifically and technologically skilled professionals to drive it, and the preparation of a scientifically and technologically informed citizenry to guide it. In turn, the Incheon Declaration for Education 2030 recommended the strengthening of STEM education as a key strategy for meeting its sustainable development goals (UNESCO, 2015).

STEM education has been pursued internationally since the mid-2000s. The UNESCO Incheon declaration, "Education 2030", addressing the fourth sustainable development goal asserts that "A focus on quality and innovation will also require strengthening science, technology, engineering and mathematics education (STEM)" (UNESCO, 2015, p. 33). Many Western nations have seen relative declines in student achievement, engagement and participation in STEM (Blackley & Howell, 2015). Lobbyists and policymakers in these countries call for a higher public understanding and perception of STEM, alongside improved teaching and learning, and increased student interest and participation, in STEM (Marginson et al., 2013). The European Union called for the nurturing of STEM skills throughout schooling in order to avoid European economies being constrained by a STEM skills shortage (Bubnick, Enneking, & Egbers, 2016). The United Kingdom promoted improvements in STEM education, through teacher training and collaboration with industry, as the solution to the national shortfall of STEM skilled employees (HM Treasury, 2011). The United States of America adopted a 5-year strategic plan titled "Federal Science, Technology, Engineering, and Mathematics (STEM) Education" (National Science and Technology Council, 2013), calling for STEM education to become a national priority, with initiatives to train 100,000 STEM teachers, and to foster school networks to better distribute STEM education resources. The Council of Canadian Academies reported to the Canadian government, recommending investment in STEM education at all levels to improve national innovation and productivity (Council of Canadian Academies, 2015). In contrast, developed Asian nations see STEM as nationally and personally important, and have experienced no decline in teaching and learning in STEM. Australia is a relative late adopter (Blackley & Howell, 2015), gaining significant momentum from 2013 with the publication of several key papers by the Australian Office of the Chief Scientist (OCS) (2013, 2014) and the Australian Industry Group (AIG) (2013, 2015). In December 2015, the "National STEM School Education Strategy 2016–2026" (Education Council, 2015) was endorsed by the Australian state and territory governments, with state- and territory-specific strategies following shortly thereafter.

There is an accepted correlation between strong performing education systems and nations with thriving economies (Marginson et al., 2013). In Australia, the urgency to improve STEM education has been largely driven by sliding performance of Australian students, both relative to other nations and, in some cases, in absolute terms (Thomson, De Bortoli et al., 2017; Thomson, Wernert, O'Grady, & Rodrigues, 2017). Moreover, fewer students are choosing to study STEM subjects at both the senior secondary and tertiary levels (Goodrum, Druhan, & Abbs, 2012; McPhan, Morony, Pegg, Cooksey, & Lynch, 2008; Morrison, Roth McDuffie, & French, 2015). This phenomenon is not unique to Australia; indeed, PISA (Programme for International Student Assessment) testing suggests that science and mathematics performance of students has also declined in recent times in other nations, including the Czech Republic, Finland, Hong Kong, Iceland, Korea, Netherlands, New Zealand, Slovak Republic and Turkey, while average performance across the OECD has not improved significantly in more than a decade (OECD, 2018; Thomson, De Bortoli et al., 2017). Furthermore, many countries, including the US and the UK, are experiencing declining enrolments in senior STEM subjects (Cooper, Berry, & Baglin, 2018; Marginson et al., 2013).

1.3 Defining STEM Education

The term "STEM education" typically refers to formal and informal education programmes from preschool to tertiary level that encompass the disciplines of science, technology, engineering and mathematics (Shanahan, Burke, & Francis, 2016). However, the definition of both STEM and STEM education is a contested space, with researchers, policymakers and practitioners holding a range of varied, and quite nuanced, perspectives on what constitutes STEM education. A significant contributor to this contention is debate around the degree and mode of integration required for effective STEM education. STEM is described as multidisciplinary, where various combinations of science, technology, engineering and mathematics are applied together while retaining their disciplinary identity, or as interdisciplinary or transdisciplinary, where disciplinary boundaries dissolve and STEM represents new ways of thinking (Kelley, 2010; Shanahan, et al., 2016). STEM integration is criticised for potentially undeserving or overlooking aspects of the component disciplines (English, 2016; Moore et al., 2014; Williams, 2011), or as impractical, given the structures and processes governing contemporary education (Shanahan, et al., 2016). Typically, STEM education policy offers little advice to resolve this debate. For example, there is no consensus amongst the seven STEM strategies from the various Australian jurisdictions as to the integrated nature of STEM education (Murphy, MacDonald, Danaia, & Wang, 2019). Debate about STEM integration is made all the more complex due to the variation in the conception of STEM education between the early childhood, primary and secondary schooling sectors. In part, this is due to the naturally integrative nature of early childhood education, versus the tendency towards subject-based programming in primary, versus the subject-driven, structural constraints of secondary and senior secondary.

There is, however, greater agreement about STEM education being applied to real-world problems. In advocating for improvements in STEM education, industry bodies and governments call for students to be equipped with skills for innovation and problem-solving (AIG, 2017; Council of Canadian Academies, 2015; Murphy et al., 2019). Similarly, researchers generally describe STEM education as involving authentic inquiry (Asunda & Mativo, 2015; Capraro & Slough, 2013; Gee & Wong, 2012). Some writers advocate moving beyond disagreement associated with the disciplines, focussing instead on what is shared amongst the various conceptions of STEM education (Shanahan, et al., 2016) and the potential for STEM to transform education into a more authentic, relevant form (Myer & Berkowicz, 2015).

In this book, we similarly eschew debate about disciplinary integration and representation. We take the stance that notions of STEM education must span the educational continuum from early childhood to senior secondary. From that stance, we posit that STEM is a human endeavour that uses the knowledge and processes of the technical disciplines (i.e. any combination of science, technology, engineering, or mathematics) to help us pose, ponder, and solve problems that are real world and authentic to our worlds. STEM education is thus the educative process of preparing individuals to do so in an ever-changing world.

1.4 About This Book

This book contains a diverse range of chapters authored by Australasian and international STEM researchers, including both education researchers and those from the STEM disciplines, and with perspectives from early childhood through to senior secondary education. Informed by our stance on STEM education, we have not sought chapters to equally represent the disciplines, but rather to explore how children can be engaged in authentic STEM learning across all stage of the learning continuum. The authors of each chapter reflect on his or her research in the area of STEM education, place that work within the overall context of research in this field, discuss how their work contributes to an understanding of the aspect/s identified above, and consider the implications of the work both theoretically and practically. It is intended that the book will serve the purpose of stretching current and ongoing thinking about STEM education, as well as sharing current knowledge in this field.

This book begins with a chapter by the Editors that introduces a conceptual framework for effective STEM education and its theoretical basis. The subsequent chapters are organised to represent a learning continuum from early childhood to senior secondary education. Chapters 3–7 represent perspectives on STEM in early childhood education and include a provocative exploration of gendered perspectives on programming and robotics in preschool education (Chap. 3); a theoretical positioning on the cultural transmission of mathematical signs through pretend play (Chap. 4); a guiding framework for meaningfully incorporating picture book pedagogies in early childhood mathematics classrooms (Chap. 5); an analysis of three international early childhood curriculum frameworks for their potential to foster STEM learning (Chap. 6); and an illustration of the role of teacher education and professional learning in promoting early childhood educators' positive dispositions towards digital technologies (Chap. 7).

The second set of chapters in this book build on this early childhood perspective to consider STEM in primary and middle years education. Chapter 8 extends the work in Chap. 7 to consider the relationship between digital technologies and numeracy development, and its place in the early primary classroom. The next four chapters explore STEM engagement from a range of perspectives, namely, engaging Indigenous learners in remote contexts (Chap. 9); supporting diverse learners, with a focus on Māori and Pāsifika students (Chap. 10); the theoretical basis for an emphasis on engagement in STEM education (Chap. 11); and an illustration of non-traditional STEM education programmes that build connections between learners and experts (Chap. 12). These chapters are complemented by an evidence-based examination of threshold concepts in primary mathematics and science education (Chap. 13).

The final suite of chapters represents transitions to secondary and senior secondary STEM education. Chapter 14 offers an empirical study of the power of primary–secondary pedagogical partnerships in supporting STEM learning. The subsequent chapter builds upon this through an examination of middle years and secondary mathematics and science pedagogy in Qatar (Chap. 15). Finally, Chap. 16 examines STEM engagement and outcomes at the senior secondary level, with a focus on rural students.

We certainly encourage any reader to engage with this book in its entirety, and there is great value in reading the chapters in order so as to appreciate the learning continuum which they represent. However, we believe this is also a book to be dissected, partitioned and utilised for a range of purposes. We trust this collection of international perspectives will simultaneously challenge, affirm and extend your thinking in relation to effective STEM education from early childhood to senior secondary education.

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Chapter 2
Sustaining STEM: A Framework for Effective STEM Education Across the Learning Continuum

Steve Murphy, Amy MacDonald and Lena Danaia

Abstract This chapter introduces the *Sustaining STEM* conceptual framework for effective STEM education that spans early childhood to senior secondary education. The framework represents three key interacting components: 1. Knowledge: the nature of STEM knowing and knowledge (for example, accessing STEM knowledge, dealing with uncertainty), rather than what should be known; 2. Skills: transdisciplinary skills beyond those of the individual STEM disciplines (for example, problem-solving, creativity, critical thinking); and 3. Engagement: the affective domain of STEM education (for example, academic emotions, motivation). Additionally, the framework highlights the need to address critical issues in STEM education, for example, transitions and trajectories, gender, rurality, socioeconomic status and cultural diversity. The chapter draws upon the available research evidence to present an informed and critical stance in relation to each of these elements of STEM education.

2.1 Introduction

There is strong political, industrial, social and educational support for STEM education (Shanahan, Burke, & Francis, 2016); however, there is no common understanding as to what constitutes effective STEM education. Cognitive aspects of STEM education have received significant attention. STEM education is commonly viewed as

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interdisciplinary (Becker & Park, 2011; Honey, Pearson, & Schweingruber, 2014; Yildirim, 2016) with the type and extent of integration being contested (Bybee, 2013; Kelley, 2010; Moore et al., 2014). Other writers concentrate on STEM education for developing complex skills such as problem-solving (Bybee, 2013; MacDonald, 2015), data modelling (English, 2016), design processes (English, King, & Smeed, 2017) and spatial reasoning (Lowrie, Downes, & Leonard, 2018). Some researchers advocate particular pedagogical approaches to nurture these capabilities, such as inquiry learning (Gee & Wong, 2012; Von Secker, 2002), problem-based learning (Asunda, 2014) and project-based learning (Capraro & Slough, 2013).

While the majority of STEM education literature focuses on developing student capabilities, there is also significant research highlighting the importance of affect in STEM education. Students' motivational beliefs and academic emotions are associated with their engagement and participation in STEM subjects, as well as their coursework selections, and long-term STEM career choice, regardless of their abilities and prior achievement (Parker, Marsh, Ciarrochi, Marshall, & Abduljabbar, 2014; Wang & Degol, 2013). There is also considerable literature exploring the development of both the cognitive and affective STEM elements across the learning continuum and in students from different genders, cultures, places and social backgrounds (McDonald, 2016).

Despite this significant and rapidly growing body of STEM education literature, there have been few attempts to draw together this work to present a comprehensive framework of effective STEM education. This chapter considers the models of STEM education that have been developed against the themes prominent in the literature: student capabilities, student dispositions, educational practices, equity, trajectories and educator capacities (Murphy, MacDonald, Danaia, & Wang, 2018). Each model makes a strong contribution to efforts to build a shared and comprehensive understanding of STEM education; however, in our opinion, each also has short-comings. The chapter then introduces the *Sustaining STEM* conceptual framework for effective STEM education, spanning from early childhood to senior secondary school. It presents an overview of three key interacting components: 1. Knowledge: the nature of STEM knowing and knowledge (for example, accessing STEM knowledge, dealing with uncertainty), rather than what should be known; 2. Skills: transdisciplinary skills beyond those of the individual STEM disciplines (for example, problem-solving, creativity, critical thinking); and 3. Engagement: the affective domain of STEM education (for example, academic emotions, motivation). Additionally, the framework highlights the need to address critical issues in STEM education, for example, transitions and trajectories, gender, rurality, socioeconomic status and cultural diversity. The chapter then considers the implications of the Sustaining STEM framework for education practices, educators, learning environments and educational leaders.

2.2 Existing Models of STEM Education

There have been attempts to draw together the research evidence and demands of STEM education to create models of STEM education best practice. These vary in theoretical underpinnings and emphasis, with each having significant strengths as well as important limitations.

Zollman (2012) presents a model of *STEM literacy* based upon Bloom's cognitive, affective and psychomotor learning theory domains. Zollman argues that STEM is a metadiscipline "based on the integration of other disciplines into a new whole" (p. 15) and that there should be "reduced concern for covering content and an increased emphasis in helping a student learn". Beyond this, there is no treatment of the acquisition or management of STEM knowledge. Zollman's view is that a STEM literate student needs to have the psychomotor skills to operate STEM technology, value and have confidence in STEM, and apply knowledge to meet their goals. Zollman draws on well-established theorists such as Piaget and Erikson but offers little contemporary STEM education research to support the *STEM literacy* model. Unlike other STEM education models, Zollman treats the development of physical skills required for STEM separately and acknowledges that psychomotor demands change quickly as technologies evolve. In Zollman's description of *STEM literacy,* there is no reference to STEM across the learning trajectory, or to equity issues in STEM education.

Roth and Van Eijck (2010) propose *Total Life* as a lens for educators and researchers working in STEM education. On the basis of over 20 years of research experience, they reject existing models (including Piagetian frameworks) as inadequate for planning and researching "learning that is lifelong, life-wide and life-deep" (p. 1031). They argue that STEM knowledge is unstable and offer a framework with three notions: knowledgeability—the capacity to mobilise and augment knowledge; débrouillardise—the capacity to learn and creatively respond to uncertainty, challenges and problems; and collective knowledge—knowledgeability through collaboration. Further, *Total Life* asserts that schools and classrooms can only be understood by considering the whole individual and the society they are part of. The approach suggests that effective STEM education fosters student dispositions and capacities to work creatively and collectively to solve complex, real-life problems. While noting the importance of learning motivation, and STEM learning for all ages and all cultures, the framework offers little guidance as to how to achieve this. Similar to Zollman, Roth and Van Eijck support their model with little contemporary research other than their own.

Rather than theorising a model of STEM education, Bybee (2013) takes a more pragmatic approach. Bybee proposes a purpose for school-based STEM education and then considers the various ways schools and educators may respond to that purpose. Bybee suggests that STEM education's purpose is for all students to develop STEM literacy, which includes knowledge, attitudes and skills to address problems and explain and draw conclusions about STEM-related issues; understandings of the characteristics and real-world impacts of the STEM disciplines; and a willingness to engage in STEM-related issues. Unlike Zollman, Bybee sees disciplinary-based knowledge as essential but argues that so are opportunities to apply this knowledge to complex, real-world problems. Bybee does not problematise knowledge as Roth and Van Eijck do, but notes the need for students to be adaptable and collaborative, with skills in systems thinking, non-routine problem-solving and self-management. In expanding on his views on STEM education, Bybee focuses on the desired degree of disciplinary integration, with little attention paid to student engagement, equity issues or STEM across the learning trajectory.

Asunda's Conceptual Framework for STEM Integration (2014) is designed to support educators of older students. It draws together four theoretical constructs—situated learning, constructivism, systems thinking and goal orientation theory—to advocate for the use of real-world problem-based learning experiences incorporating design-related components. The framework addresses both student capabilities and engagement within the bounds of the four theoretical constructs and thus overlooks some key aspects of STEM engagement such as student autonomy and relatedness. As a model with an explicit vocational focus, the framework makes no claim to addressing the demands of early childhood education and pays no explicit attention to STEM-related equity issues.

MacDonald (2015) offers an explicitly early childhood view of STEM education. The everyday nature of STEM is emphasised and the STEM disciplines seen as most meaningful when explored together. MacDonald advocates child-led "playful pedagogies" that encourage the development of skills that underpin problem posing and problem-solving, such as "curiosity, creativity, flexibility and adaptability" (p. 11) and "powerful processes" that assist children to develop their STEM knowledge and STEM inquiry skills. The model does not present the child's STEM engagement as problematic, but rather focuses attention on the early childhood educator's STEM engagement, encouraging educator's to view themselves as embodying STEM.

None of the existing models adequately address all aspects of STEM education prominent in the literature. While all models consider the role of affect in STEM education, they tend to take either a narrow or superficial view of engagement. None of the models adequately address an individual's entire learning trajectory or the significant equity issues confronting STEM education. There remains a need for an evidence-based conceptual framework of effective STEM education that spans from early childhood to senior secondary. We propose that the Sustaining STEM framework detailed in the subsequent sections of this chapter is a potential way to address this need.

2.3 Sustaining STEM—A Conceptual Framework for Effective STEM Education

STEM education aims to support the development of citizens who are confident and competent using STEM in their everyday lives, as active citizens, and in STEM careers (Office of the Chief Scientist [OCS], 2013). In the conceptual framework we are proposing, we refer to this as becoming “STEM capable”. Being STEM capable requires individuals to have developed in three interrelated and interacting domains that we have labelled STEM knowledge, STEM skills and STEM engagement. Becoming STEM capable begins from early childhood and continues throughout schooling. Further, gender, culture, social background and location need to be considered when fostering students’ STEM dispositions and capabilities.

In developing this stance, we draw on broad understandings of STEM from differing perspectives. This framework draws together research literature from STEM education–literature pertaining to STEM in an integrated manner as well as drawing on literature related to the individual disciplines. It also draws together perspectives across the trajectory of STEM education from early childhood through to senior secondary and beyond. Further, it considers research into STEM education for females, students of different cultures and racial backgrounds, students from rural and remote areas, and students from different socioeconomic backgrounds.

2.3.1 STEM Knowledge

STEM education is called upon to prepare learners for a complex and technological world with an unknown future. The information they need to meet STEM challenges in this world is interdisciplinary, evolving and uncertain (Roth & van Eijck, 2010). Given this, the Sustaining STEM framework focuses on the nature of knowing and knowledge, rather than on *what* should be known.

To be STEM capable, learners need to develop strong foundational knowledge of the STEM disciplines, but more particularly they need to understand that knowledge is transferable and that the disciplines work together to help understand the real world (OCS, 2013). Mathematics helps the learner to recognise patterns, and represent and model phenomena associated with STEM problems. Science provides guidance and background for cause and effect exploration. Engineering offers systems for solving immediate problems, accounting for uncertainty, constraints and aesthetics. Technology provides the learner with processes for the development of products to meet real-world needs. Through demonstrating the fluidity of knowledge and breaking down disciplinary boundaries, STEM education helps the learner access more authentic forms of knowledge (Roth & van Eijck, 2010).

STEM capable learners develop the ability to use knowledge flexibly and purposefully to respond to real-world experiences, what Roth and van Eijck (2010) would describe as ‘knowledgeability’. They can determine what information they have is relevant to a particular challenge, what information is still required, and choose strategies to access and assess it. They make strategic collective use of knowledge, collaborating with others who have expertise different to their own. They have sophisticated views about the certainty of STEM knowledge, understanding that some things are known, while others are, and may remain, uncertain (Louca, Elby, Hammer, & Kagey, 2004), and still others may be superseded (Dunaway, 2011). Essential to this way of knowing is the ability to communicate and collaborate, as well as the creativity and critical thinking skills to make connections between sources of information, and to critique knowledge.

2.3.2 STEM Skills

STEM capable individuals have the skills to pose, ponder and solve STEM-related problems that are real and authentic to their personal worlds. Industry and governments call for STEM education to equip students with "STEM skills" with little guidance as to what these skills may be (for example, Australian Industry Group [AIG], 2015; CEDEFOP, 2014; Morgan & Kirby, 2016). Some authors have used employer surveys to identify extensive lists of STEM skills required by STEM industries (for example, Jang, 2016; Prinsley & Baranyai, 2015). Others have aimed for a more manageable set of STEM skills by drawing on the twenty-first-century skills (for example, Bybee, 2013). Many researchers focus on the skills associated with complex problem-solving and the STEM processes implemented to innovate and solve problems (for example, Asunda, 2014; English et al., 2017).

STEM capable students need to develop the skills required to tackle real-world problems that can be largely understood and solved through the STEM disciplines. STEM problem-solving is complex, dealing with problems that are dynamic, involve uncertainty and have multiple possible solutions (Csapó & Funke, 2017). When problem-solving, STEM learners follow an iterative process with predictable steps that are part of real-world STEM processes, such as the Engineering Design Process (English et al., 2017), Design Process (Dooren, Boshuizen, Merriënboer, Asselbergs, & Dorst, 2014) and Computational Thinking (Shute, Sun, & Asbell-Clarke, 2017): identifying and describing a problem, generating and assessing possible solutions, and trialling, evaluating and refining a plan. Through this process, STEM capable students exercise the creativity to generate potential solutions, the critical thinking to analyse systems and solutions, and the complex communication and collaboration skills required to engage in such problem-solving activities with others (Bybee, 2013).

2.3.3 STEM Engagement

STEM engagement is given less attention in policy and literature than STEM capabilities. However, individuals need more than adequate STEM knowledge of their world, and a STEM skillset. They need the inclination and confidence to apply their STEM knowledge and exercise their STEM skills in their personal and professional lives. Having the motivation and self-assurance to engage with STEM is a crucial aspect of being STEM capable and distinguishes being STEM capable from being merely STEM literate.

STEM engagement refers to students' commitment to involvement in STEM learning activities (Christenson, Reschly, & Wylie, 2012). Engagement is a multifaceted outcome, encompassing cognitive, behavioural and emotional aspects (Fredricks, Blumenfeld, & Paris, 2004). Behavioural engagement centres on participation and involves behaviours such as persistence, effort and concentration in STEM (Fredricks et al., 2004). Emotional engagement influences a learner's connectedness to a task or situation and impacts upon their willingness to work. It involves both positive and negative responses to learning activities, peers, educators and learning institutions. Cognitive engagement centres on the notion of investment, where learners concentrate and persist in order to understand complex notions and develop difficult skills.

The pathway towards engagement lies in learner motivation towards STEM. Several broad and interrelated motivational constructs can be drawn upon to build engagement for STEM learners (Murphy, MacDonald, Wang, & Danaia, 2019). Most prominent among the motivational literature is the interaction between self-concept and self-efficacy with the value of STEM and STEM learning. Self-concept and self-efficacy will determine students' expectancies of success in STEM activities. Self-efficacy and self-concept address the questions of "Can I do well in this task?" or "Can I do well in STEM learning?", whereas the question of "*Why* should I do this task?" refers to the *values* that learners attach to the activities (Eccles et al., 1983; Schunk, Pintrich, & Meece, 2008). Learners may be motivated by different task values. Attainment value is the importance learners place on doing well on a task (Eccles, 2005). Interest value relates to the enjoyment a learner takes from participating in a task (Eccles, 2005). Utility value is the usefulness, particularly long term, of the task as perceived by the learner (Eccles, 2005; Hulleman, Durik, Schweigert & Harackiewicz, 2008). Finally, cost value is essentially about weighing up the amount of effort needed to complete the task versus the impact of potential failure (Eccles et al., 1983).

Relatedness and autonomy are two additional motivational constructs that contribute to STEM engagement. Relatedness involves the learner feeling connected to their learning environment and their educators and peers (Ryan & Deci, 2000). Autonomy means that students have an option and the opportunity to exercise control over their learning environment and processes (Carmichael, Muir, & Callingham, 2017). Accounting for both these constructs in STEM education creates an autonomous supportive learning environment where students are provided a degree of freedom with the security of knowing they are supported and can seek assistance as required (Carmichael et al., 2017).

Finally, the motivational constructs around beliefs about intelligence and achievement goals also influence learner STEM engagement. Achievement goals may be driven by either performance or mastery. Performance involves the learner comparing their own success to others, whereas mastery focuses a learner's own learning, understanding and development of academic competence (Ames, 1992; Schunk et al., 2008). Related to this are beliefs about intelligence. Learners adopting a fixed mindset believe their intelligence is unchangeable and uncontrollable (Dweck & Leggett, 1988), whereas students with a growth mindset believe their intelligence is malleable and controllable.

2.3.4 STEM Across the Learning Continuum

The Sustaining STEM model emphasises that these three domains of STEM education must be developed throughout a learner's education. Effective STEM education develops STEM ways of knowing for learners from early childhood through to tertiary education. For young children, the purpose of knowing is immediate, and information sources more accessible, for example, solving design challenges using blocks with support from educators (Christenson & James, 2015). In primary school, children can readily be introduced to meaningful STEM challenges in their immediate communities, and access knowledge from a variety of sources including data analysis and experts in relevant fields (English & Mousoulides, 2015). By secondary school, learners can make sophisticated use of knowledge and data with purposes that have social significance (Kelley, Brenner, & Pieper, 2010).

Learners of all ages should also be employing STEM processes across the learning trajectory, developing STEM skills. Children in early childhood engage in engineering behaviours, scientific inquiry and problem-solving through play (Bagiati & Evangelou, 2016; Dejonckheere, De Wit, Van de Keere, & Vervaet, 2016; Solis, Curtis, & Hayes-Messinger, 2017). Students in early primary school can work collaboratively using inquiry learning to investigate authentic problem-based projects and design tasks (Bubnick, Enneking, & Egbers, 2016; Zoller, 2011). Later in primary school, through to secondary school, students can design, construct and evaluate both physical and digital solutions to real-world problems (Akcaoglu, 2016; Ardito, Mosley, & Scollins, 2014; Ellison, Evans, & Pike, 2016; English et al., 2017; Quigley & Herro, 2016). In secondary school, students can employ mathematical modelling of STEM problems and engage in STEM projects beyond the school environment (Dixon & Brown, 2012; Knezek, Christensen, Tyler-Wood, & Periathiruvadi, 2013; Magiera, 2013; Schuchardt & Schunn, 2016).

STEM engagement also needs to be fostered throughout the educational journey, and particularly at key transition points. Students begin forming their attitudes towards STEM careers in early primary school with STEM aspirations relatively established by early secondary school (Archer, Osborne, DeWitt, & Dillon, 2013; DeWitt, Archer, & Osborne, 2013). Positive contacts with STEM from an early age can have long-term impact on engagement; however, negative school experiences can be detrimental (OECD Global Science Forum, 2006). Negative attitudes and emotions towards mathematics have been reported as being ingrained for some students by the end of the early years of schooling (Larkin & Jorgensen, 2016). Student attitudes towards STEM tend to become fixed for most students in the early years of secondary education (Archer, et al., 2013; McPhan, Morony, Pegg, Cooksey, & Lynch, 2008; Sheldrake, Mujtaba, & Reiss, 2017; Wang, Chow, Degol, & Eccles, 2017). Student attitudes towards STEM subjects decline through the first year of high school (Kennedy, Quinn, & Lyons, 2018) and a general downward trend in student interest in mathematics continues through early secondary school (Frenzel, Goetz, Pekrun, & Watt, 2010).

2.3.5 STEM for All Learners

By profiling the domains of knowledge, skills and engagement as essential for effective STEM education, the Sustaining STEM framework offers a structure for examining and addressing the significant equity issues confronting STEM education. Issues associated with gender, socioeconomic status (SES), culture and rurality are all present in the STEM education literature. Girls are less likely to choose STEM subjects (OECD Global Science Forum, 2006) and tend to have lower maths self-concept (Frenzel et al., 2010; Guo, Parker, Marsh, & Morin, 2015). Students from low SES backgrounds have gaps in their STEM knowledge (Stacey, Vincent, Stephens, & Holton, 2015), and SES can be predictive of the development of executive functions required for problem-solving (Blums, Belsky, Grimm, & Chen, 2017). Further, students from low SES backgrounds are more likely to become disengaged with STEM studies, and less likely to choose advanced STEM subjects or aspire to STEM careers (Cooper, Berry, & Baglin, 2018; Martin, Way, Bobis, & Anderson, 2015; McPhan et al., 2008; Thomson, De Bortoli, & Underwood, 2017). Students from non-European language backgrounds can have difficulty with STEM terminology (Edmonds-Wathen, 2014). Certain STEM learning contexts limit Indigenous Australian students' ability to demonstrate and develop their STEM skills (Grootenboer & Sullivan, 2013). Students from rural schools perform more poorly than their metropolitan counterparts in STEM testing, whereas students from metropolitan schools are more likely to enjoy STEM learning, select advanced STEM subjects and aspire to STEM-related careers (Lyons & Quinn, 2010; Murphy, 2018a, 2018b, 2019; Thomson et al., 2017).

The Sustaining STEM framework recognises that the development of STEM knowledge, skills and engagement are all shaped by learners' social, cultural, historical and language backgrounds (Edmonds-Wathen, 2014; Fragkiadaki, Fleer, & Ravanis, 2017; Jorgensen, 2015). For example, the Sami, an Indigenous people of the Arctic, view time as cyclical, conceive space as circular and connected to nature, and see knowledge as held in common and generated through practical experience (Keskitalo, Uusiautti, & Maatta, 2012). Ewing (2014) found that the daily community life and cultural practices of Indigenous Australian students impact their ways of knowing mathematics. STEM educators can use the particular differences in backgrounds of students to enhance STEM learning. For example, Owens (2015) found that the lives of students in particular Papua New Guinean cultures nurtured their visuospatial skills and that educators could structure STEM learning to capitalise on these skills for problem-solving. Stacey et al. (2015) suggest that female students, Indigenous Australian students and low SES students all have better self-concept and greater interest in STEM when learning emphasises cooperation over competition and is contextualised to their worlds. By emphasising the three interaction domains of knowledge, skills and engagement, the Sustaining STEM framework captures the key considerations in developing STEM education for *all* learners.

2.4 STEM Practices, Educators, Learning Environments and Leaders

The goal of effective STEM education is to develop STEM capable individuals. All learners, at all stages, need to be fully engaged in activities that allow them to use STEM skills and knowledge when working on complex real-world tasks. Educators need the capacity and confidence to facilitate learning that is dynamic, student-centred and utilises the methods and processes from across the STEM disciplines. Learning environments need to be shaped, resourced and connected to the wider world to enable such educational practices. This section discusses the qualities of educational practices, educators and learning environments required to develop STEM capable individuals.

2.4.1 STEM Educational Practices

There are several related pedagogical practices represented in the literature that develop and sustain STEM capacities and engagement through working collectively on complex tasks set in real-world contexts, including Problem-Based Learning (PBL) (Asunda, 2014), Project-Based Learning (PjBL) (Capraro & Slough, 2013), Design Tasks (English et al., 2017) and Inquiry-Based Learning (IBL) (Makar & Fielding-Wells, 2018). These approaches all provide a framework to guide students to draw on disciplinary understandings and skills, actively construct knowledge, and generate potential solutions. These structured approaches to inquiry avoid the criticisms levelled at more open inquiry pedagogies such as "discovery learning" (Makar & Fielding-Wells, 2018). These practices are associated with improved skills in communication, collaboration, creativity, critical thinking and problem-solving (Hathcock, Dickerson, Eckhoff, & Katsioloudis, 2015; Makar & Fielding-Wells, 2018; Morrison, Roth McDuffie, & French, 2015; Mosley, Ardito, & Scollins, 2016; Yanyan, Zhinan, Menglu, & Ting-Wen, 2016). They are seen to increase student engagement and motivation in STEM, including by bolstering self-efficacy (Fielding-Wells, O'Brien, & Makar, 2017), increasing task-value with personally relevant and/or real-world tasks (Kelley et al., 2010; Redmond et al., 2011) and supporting student autonomy (Selmer, Rye, Malone, Fernandez, & Trebino, 2014; Strimel, 2014).

These practices have been implemented right across the learning continuum. Design tasks begin as construction play using materials such as blocks or Lego in early childhood (Bagiati & Evangelou, 2016; Torres-Crespo, Kraatz, & Pallansch, 2014) and become more complex problem-solving tasks associated with aerospace engineering, biotechnical engineering or digital electronics in the later years of secondary school (Dixon & Brown, 2012). Real-world learning has been investigated from the early years, where tasks are personally interesting and the audience is limited to family and friends (for example, Christenson & James, 2015), through to later years, where broader real-world challenges are confronted and the audience is the wider community (for example, Kelley et al., 2010). Providing learners some agency over their learning has been found to impact positively on student learning and engagement across the learning continuum, from early school (Bubnick et al., 2016) through to high school (Lou, Tsai, Tseng, & Shih, 2014).

Elements of these practices have also shown the potential to address equity issues in STEM. Learning contexts connected to the local resources and lives of students better engage Indigenous and rural students (Centre for Education Statistics and Evaluation, 2013; Ewing, 2014). Collaborative STEM learning activities are more effective for girls and Indigenous students (Ewing, 2014; Stacey et al., 2015).

2.4.2 STEM Educators

Educators themselves need to be STEM capable, as well as possess additional characteristics that allow them to foster STEM knowledge, skills and engagement in their students through appropriate educational practices. Educators draw on a range of learning theories to inform their practice (Starkey, 2012). The STEM capable educator draws primarily on three related learning theories: personal constructivism, social constructivism (Skamp & Preston, 2018) and connectivism (Starkey, 2012). Personal constructivism sees individuals building understanding through interaction with the material environment (Skamp & Preston, 2018).

Social constructivism sees learning driven by communication with others and interaction with the social environment. Connectivism sees technology extending interactions beyond the immediate physical environment, and knowledge creation involving making connections between people and information sources (Starkey, 2012). Connectivism views knowledge as unstable, with new understandings evolving and others being superseded or becoming redundant. Between them, these learning theories underpin the Sustaining STEM framework, positioning knowledge as uncertain and socially constructed, STEM skills as developed through interaction with the real world, and engagement fostered through authentic learning activities and social relationships.

Moreover, a STEM capable educator believes that STEM capabilities and attitudes can be developed in all learners, across all stages of learning. They believe that young children are curious, creative STEM problem-solvers (MacDonald, 2015). They understand that children arrive in primary school with the capacity to engage in quite sophisticated inquiry and engineering thinking (Bagiati & Evangelou, 2016). They know that students begin secondary school capable of tackling STEM problems with broad social significance (English et al., 2017). They understand that connecting STEM learning to a students' background and context can support the development of both their STEM capabilities and engagement (Stacey et al., 2015).

Given the dynamic nature of STEM, STEM capable educators need to work continually and collaboratively to develop both content knowledge and pedagogical knowledge to effectively support STEM learning—across the disciplines, for all students and across all stages of learning. This challenge differs somewhat depending on the education sector of the educator. Park, Dimitrov, Patterson and Park (2017) found that the majority of early childhood educators undervalued the importance of STEM education and have low STEM knowledge and low readiness to teach STEM, though a significant group reported positive beliefs about teaching STEM. Primary teachers tend to receive greater training in teaching practice but less in specialist content knowledge compared to secondary school teachers (OECD, 2018). Consequently, in general, early childhood and primary school STEM educators have stronger STEM pedagogical knowledge but need more skills working with STEM content knowledge, while secondary teachers are required to adopt more non-traditional STEM pedagogies (Forbes & Skamp, 2016; Myers & Berkowicz, 2015).

2.4.3 STEM Learning Environments

The learning environment, both within and beyond schools and learning centres, contributes strongly to developing STEM capable learners, facilitating STEM education practices and supporting STEM educators. STEM education practices can be supported through policy, resourcing and networking. STEM practices, such as IBL, PBL and PjBL, can be facilitated by access to low-cost and recycled materials in the classroom (Lee, 2014; Llewellyn, Pray, De Rose, & Ottman, 2016), and by establishing resource-rich environments, such as maker spaces (Sheffield, Koul, Blackley, & Maynard, 2017). Some schools have adopted school-wide approaches to problem-solving (Hefty, 2015; Marshall, McGee, McLaren, & Veal, 2011; McCarthy & Slater, 2010; Morrison et al., 2015). In secondary schools, STEM learning and engagement is enhanced through resources and connections beyond the classroom, through projects aiming to contribute to the local community, or make a positive impact on real-world issues (Dixon & Brown, 2012; Kelley et al., 2010; Knezek et al., 2013). Partnerships between primary and secondary school, and community groups, industries, or universities have also been found to support STEM education, either through improved student engagement or by providing expert knowledge and skills (for example, Ardito et al., 2014; English et al., 2017; McDonald & Howell, 2012).

The use of digital technologies features strongly in the literature as a way to build STEM skills and improve STEM engagement. For example, the use of robotics and simulation software such as *Minecraft* fosters problem-solving and creativity across learning stages (Ardito et al., 2014; Ellison et al., 2016; McDonald & Howell, 2012; Mosley et al., 2016; Nemiro, Larriva & Jawaharlal, 2017). In secondary school, digital technologies have been used for real-world modelling and design tasks (Akcaoglu, 2016; Bevan, 2017; Quigley & Herro, 2016).

2.4.4 STEM Leaders

Educational leaders play a key role in supporting STEM educators and developing STEM learning environments. Myers and Berkowicz's (2015) "reservoirs of leadership" that leaders must draw upon to lead effective STEM education has parallels with the Sustaining STEM framework. Leaders must have knowledge of STEM, which involves understanding STEM's meaning and potential; skills to facilitate collaborative action on STEM, including coalition-building skills; and a vision and passion for STEM, including a willingness to take risks. Other writers hold similar views. Lochmiller, Huggins & Acker-Hocevar (2012) argued that effective STEM leaders cultivate a common understanding of STEM's importance and of doing well in STEM education, identify and leverage resources to facilitate effective STEM pedagogies, and strategically develop partnerships with the community, industry and other educational institutions to enrich the STEM learning environment. Gehrke and Kezar (2016) contend that STEM leaders need adequate knowledge to be able to collaboratively develop and articulate a STEM education philosophy and the skills to build the trust and high levels of collaboration required for sustained collective action to improve STEM education. STEM leaders promote and facilitate effective STEM education practices, particularly by supporting the development of STEM educator capacities, and allowing access to, and appropriately resourcing, rich STEM learning environments.

2.5 Conclusion

By drawing on extensive contemporary literature and providing a structure to address the STEM education needs of all learners at all stages of learning, the Sustaining STEM framework provides a unique structure for investigating and describing effective STEM education. The framework presents a triumvirate of equal and interacting domains: knowledge, skills and engagement. It views STEM knowledge as unstable, evolving and created collaboratively, encouraging a focus on ways of knowing, rather than what is known. STEM skills are those associated with the complex, iterative processes of STEM, and include creativity, critical thinking and problem-solving skills. The framework emphasises the importance of STEM engagement, drawing on constructs of motivation and academic emotions found to impact on STEM learning. These three domains allow for the effective exploration of STEM education for all learners, of different genders, cultures and social backgrounds, from early childhood through to secondary school and beyond.

The Sustaining STEM framework supports the examination and development of educational practice. To become STEM capable, learners need to be provided with opportunities to pose, ponder and solve problems relevant to their worlds, by working with others and utilising the STEM disciplines. Pedagogies such as PBL, PjBL, IBL and design tasks have the potential to provide such opportunities and to foster engagement with STEM. Educators need beliefs, skills and dispositions appropriate to developing the three domains in their students. They need to believe all students, at all stages of learning, are capable of engaging with STEM learning, and they themselves need the skills to support learner-centred, problem-based pedagogies. Finally, STEM leaders need to work with educators to develop rich learning environments that facilitate these pedagogies, particularly providing opportunities for authentic learning experiences for their students.

The Sustaining STEM framework is intended to support the development and evaluation of STEM education. Though only in its infancy, the framework has already been employed effectively in a variety of contexts, including in STEM education policy analysis (Murphy et al., 2018), in the evaluation of an early childhood STEM education programme (MacDonald, Danaia, Sikder, & Huser, 2019) and in international curriculum analysis (MacDonald & Huser, Chapter 6 in this volume). The authors are currently using the framework to guide the investigation of rural secondary schools achieving STEM education success and to develop undergraduate and masters level subjects about STEM education for preservice teachers. As the framework captures the key themes of STEM education represented in contemporary literature, it is believed that researchers and educators alike will find it a useful tool for guiding their work, leading to the improvement of STEM education for *all* students, throughout their learning journey.

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Chapter 3
What Happens When the Robot Gets Eyelashes? Gender Perspective on Programming in Preschool

Mia Heikkilä

Abstract In the revised Swedish national preschool curriculum the idea of educating children in four specific disciplines is formed as an interdisciplinary theme with an applied approach to STEM. Programming, as a form of applied mathematics and technology, is a growing feature in preschools today, but little is known from research about coding with young children (Mannila, 2017). This chapter presents an analysis of a case study of how teaching and learning programming in early childhood education is done and the analysis elaborates on gender aspects of this. Multimodality, as well as feminist poststructuralist perspectives, is considered relevant analytical tools in order to understand the interaction and communication going on in the sequences of teaching and learning on programming (Francis, 2002; Kress, 2003; Selander, 2017). The results of the analysis show both how programming creates great interest amongst the children, illustrated by children's patience and willingness to follow the content of the sequences, and also how programming risks to become more boy-friendly in educational practice.

3.1 Introduction

Just exactly what happens in a preschool setting when a robot that the group is working with gets eyelashes put on is of course difficult to answer, but interesting to note and think thoroughly about. In this chapter, this question will be discussed with the help of two concrete examples from a preschool setting. I will also shed light on how gender equality can be realised in the growing digitisation era, that is, how gender aspects of teaching and learning and digitisation can be combined in early childhood settings. Questions about how gender is made in relation to digitisation are posed. This is important as it relates to Swedish preschools' assignment to actively work for gender equality in order to prevent an imbalance between girls and boys both in

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preschool's activities and also concerning STEM activities, here exemplified by programming. This will be done by looking at gender patterns as a part of programming, an aspect of the digitisation work in preschool.

An increased focus on digital competence, including the introduction of programming in preschools and in early ages, is still a rather new phenomenon. Consequently, there is little prior research in Sweden (where this research was conducted) or internationally. For instance, it is not possible to find any study similar to the one presented here, and a review of the international literature on this topic, programming in preschools, in general revealed only a few studies. Still, many preschools add programming to their everyday practice, despite the lack of supportive research and previous comprehensive experience. The rationale for doing so is multifaceted. On the one hand, programming can be seen as a didactic tool for developing digital skills and computational thinking in different ways in preschool. Programming in preschool can also be a means of finding new ways for learning, motivating the children and increasing their interest and curiosity (Fesakis et al., 2013). Children's learning and development form the basis on which planning, implementation and evaluation is designed and carried out.

Gender patterns that show that girls and boys get different access to, and conditions for, learning and developing in preschool are understood in this chapter as a lack of gender equality (Heikkilä, 2015). This is something that needs to be addressed within a preschool's curriculum, so that all children in preschool get equal access, and as equal conditions as possible, to learn and develop. Research has long shown that children in preschool are given different opportunities for learning and development because of their gender (e.g., Dolk, 2013; Hellman, 2010).

Gender equality in preschool, in relation to digitalisation and programming, is similar to gender awareness in other areas in preschools. However, it is possible to raise specific challenges that may exist in relation to digitalisation, and therefore, I will exemplify and discuss the risks involved in making programming something for boys more than for girls. The chapter highlights the new challenges that digitalisation can entail, not the least for preschool teachers.

3.2 An Example Study on Gender Perceptions

I want, though, to start with an example from a study that concerns higher education, to reflect on whether there is a kind of connection between the preschool's gender-promoting work and the university's. Even though the length of time from when an individual attends preschool until s/he possibly starts university education is quite long, the patterns and events that take place in both contexts can still be important to look at. Taking a larger educational perspective, it is possible to see a relationship between what is happening in preschool and what may happen at university, and the pattern shown here is established somewhere along the way. The discourses on gender, gender equality and relationships that exist in both parts of the education system can resemble each other in content, even if they appear in different ways.

Within the framework of the study, the research team interviewed students who attended study programmes where they were in a strong gender minority. These were female students who went on a Master's programme with a specialisation in computer science (a five-year engineering programme where most students are men). Programming is a significant part of the study programme, and the female students in the interviews described how they did not feel comfortable with the programming parts of the curriculum, how they did not have the same prerequisites as the male students and how they did not always keep up with the teaching. The teachers at the college seemed to assume that the students would have some prior knowledge of programming (although there are no such formal admission requirements) and their expectations proved to be in line with the male students' prior knowledge. The female students talked about, and gave several examples of, how their male fellow students took over, and ignored their suggestions and ideas, when it came to programming. One of the female participants gave the following example:

> I study with a guy friend, and he can drive over me quite often. When I give an idea on a solution, he thinks it is bad and so we go on to his idea, because I have always felt that I am not right, or yes, have been told that I am not right. Who does that? Then I trust myself less and then I like to go on his options because it feels better. But it has been proved very many times that it actually was my idea or my alternative that was the right one.

Another woman offered a further example of how a female student's knowledge within the framework of engineering studies was undervalued:

> Yes, there were many who had a difficulty because I was right. Yes, one example was when I was studying myself and not with someone, and a guy suddenly comes up and starts to look in my book, over my shoulder, and just pointing, just saying "you're wrong". And he does not know what task I am doing, he does not know what I am doing, he would only state that I was wrong. And I knew I wasn't. And then he came back a while later and just said "no, you weren't wrong". So it feels like some, yes, just wanted to point out that I can't be right.

Both of these examples reflect a view that the female students were not expected to be able to programme, even though they had been studying and although they might not have been comfortable with learning about programming initially during their studies. The male participants had the view that they knew more about programming compared with their female colleagues even though this may not have been true in reality. The male participants also communicate their views to the females who were learning to program.

The purpose of describing this study and giving it space in a chapter about STEM and preschools is that it can make us reflect on discourses about women and technology where women are often placed, and place themselves, in a position where they are not seen as adequate and where they are ignored. The examples can make us reflect that gender inequality is shaped over a period of time, not only in moments when you are in preschool. It starts here, if it starts. Traditionally, the predominant gender discourse is that men have, to a greater extent, and for a longer time, been the group that stood for "the technical", the difficult and the somewhat abstract, elusive. Based on these stereotypical images about the technology corner, the programmer and the technology innovator have emerged, and in creating this picture women have largely been absent.

This is one reason why gender awareness within the framework of programming is needed in preschool, since, in one way, it can be argued that technology, programming and digitisation have, from the start, a gender coding that leans on the more so-called masculine. It is, of course, difficult to know if this applies to all parts of the digitalisation of the preschool, but there is a risk that as soon as the teachers in the preschool think about technology, programming, mathematics and digitalisation—areas that are often associated with each other—they think that the boys are better at it than the girls, or perhaps even more suitable. The teacher is most often a women herself, which might affect her self-confidence in including these areas at all. Therefore, there is a need for studies with a gender lens looking at how these new areas are received in preschools so that all children can be included in the digitisation transformation that the preschool as an institution is part of.

3.3 Programming in Preschool

Introducing programming at an early age is not new (see Clements & Gullo (1984) and Mannila (2017) for examples of effort to teach programming in the 1980s), but one can argue that programming at this level lacks theoretical concepts connected to learning (Heikkilä & Mannila, 2018). Papert (1971) and colleagues introduced the LOGO programming language in 1967 as a tool for children to learn to program. Papert argued that technology should not be used to process children, but rather that children should learn to manipulate, expand and use technology in projects, thereby learning to understand and control their world. Programming is by nature a creative activity (Papert & Harel, 1991). Papert's programming language LOGO is often associated with a turtle that was controlled by simple command, and many of the programming tools and environments developed for young learners today are based on the same principles (e.g., simple robots such as Bee-Bot and Blue-Bot, and apps such as *Kodable* and *Lightbot*).

In preschools, the goal is not to teach programming as an intrinsic or separate subject but to focus on the other abilities that you develop while engaging in programming activities, such as algorithms, logical thinking and debugging, as well as on the opportunities to use programming as a tool for being creative and making things. These abilities are often collected under the umbrella term *computational thinking* (CT), which was introduced by Papert (1980) almost 40 years ago but has received particular attention during the last 10 years, following an influential article by Wing (2006). Wing emphasizes the importance of learning strategies and skills, which help in using computers for what they are good at, so that we, humans, can focus on what we are good at. While CT is often framed around a set of concepts, research has shown that this is not sufficient to represent students' learning: rather CT is also about practices (experimenting and iterating: testing and debugging; reusing and remixing; and abstracting and modularising) and perspectives (expressing, connecting and questioning) (Brennan & Resnick, 2012).

As mentioned above, the research base on programming in early ages is still rather limited. International studies on programming at preschool level emphasize the knowledge areas that children develop when engaging in activities related to robotics and programming. In a meta-study, Toh, Causo, Tzuo, Chen and Yeo (2016) found that these types of activities develop children's cognitive, conceptual, linguistic and social skills by focusing on, for instance, problem-solving, logical thinking, collaboration and a structured way of working and presentation. Bers, Flannery, Kazakoff and Sullivan (2013) found that children from the age of four can take in programming instruction and develop their problem-solving skills related to computational thinking, coding and robotics.

While programming per se can be seen as an abstract activity, physical artefacts such as robots make the activity more concrete while simultaneously also encouraging collaboration around the programming task at hand. Bateman, Carr and Gunn (2017) discuss how objects in children's learning environments are crucial for children's learning and how technological objects work as "physical props" supporting learning processes (Kanaki & Kalogiannakis, 2018). Levy and Mioduser (2010) describe how children explore the possibilities of the robot in a playful and curious manner. They also show how this, for instance, resulted in children making plans and predictable actions in order to make the robots act in a desired way. Sullivan, Kazakoff and Bers (2013) show how children can design, build and program robots after a limited time of instruction. This could imply that children are susceptible to more than merely very basic instruction in programming. Sullivan et al. (2013) go on to discuss how these results could aid in developing programming instruction, for instance by integrating it with mathematics and using programming for language development.

In another study, Kazakoff, Sullivan and Bers (2013) show how sequencing, which can be considered an important skill in both mathematics and early reading comprehension, can be developed through programming. They also discuss how the sequencing skills needed when programming can be supported by children's ability to think in terms of sequences as a result of their experience from stories, which commonly build on a sequence of events. The corresponding sequential way of working is one of the fundamental concepts in programming, together with conditionals (making it possible for a program to do different things based on the current situation) and repetitions (making it possible to repeat a part of the program several times).

Digital tools are a natural part of children's everyday life, both at home and at preschool. As always when choosing an activity, tool or teaching approach, it is important to have a clear focus and goal. For instance, Palmér and van Bommel (2016) point out that it takes thorough planning for the teaching activities to focus on the content at hand (in their case mathematics) and not technology per se. Cejka, Rogers and Portsmore (2006) show the importance of teachers receiving appropriate and sufficient professional development in order to be able to develop content and form for introducing programming to younger children.

3.4 How Can Communication, Learning, Gender and Programming be Understood in Relation to Each Other? Theoretical Framing of the Chapter

There are a number of different perspectives to apply to the very large and wide-ranging concepts and contexts that communication, learning, gender and programming constitute. The theoretical perspectives used in this chapter are a combination of a number of different perspectives that originate from poststructuralist theories.

In the analysis of the empirical material that will be presented below, where video films were collected in a research project on programming in preschool, a multimodal perspective was used (Kress, 2003, 2010) to understand what happened in the communication between the children and the preschool teachers. In the interpretation of the content of the teaching, that is, how programming as a subject content was problematised and highlighted, earlier studies were used from the programming area (see, e.g., Åkerfeldt, Kjällander & Selander, 2018; Mannila, 2017). Feminist theories were also used (Davies, 2003; Francis & Skelton, 2001) to focus the analysis on the gender aspects of teaching, that is, how gender can be understood as part of the communication that takes place and how the teaching is formed.

There is an intricate and intertwined connection between both communicative aspects of teaching and content aspects. The content of the teaching can be said to influence how communication is constituted, built-up and appears in the teaching situations, and that there are gender aspects as part of that communication. Communication in teaching is never neutral or something that only becomes as it becomes (Kress, 2003; Säljö, 2010). There are always discursive and contextual aspects of the communication, which shows how the participants talk, who gets to speak, in what order they get to speak, who takes the most bodily space, who is heard the most and whose understanding of the situation is given validity. In these discursive aspects, gender norms are also an important part. The participants' understanding of girls and boys, women and men, exists as a base in the context. This understanding is then reflected in the content of the moment, in the case of this study, in connection with programming in preschool.

Multimodality is seen as a relevant analytical tool and perspective in order to more deeply understand the interaction and communication going on in the sequences of teaching and learning programming (Kress, 2003, 2010). In such an analysis it is also possible to highlight social norms, such as gender norms, and discuss how they appear and are being negotiated and constructed in and by multimodal communication. Multimodal perspectives can contribute to analytically describing how teaching and learning as a social phenomenon is established as meaning making processes. This can be done by creating modal complexes where meaning making in a social semiotic understanding implies learning (Kress, 2010, 2017). Modal complexes are never arbitrary but vary extensively in social practice and need to be empirically studied in relation to different aspects of social life, such as teaching and learning. Empirical studies such as this one, of how modal complexes are constituted and shows children's gender patterns, can present the complexity of social life, and also the complexity of early childhood education (ECE) and learning—not putting verbal or written language in the centre of how communication is realised.

Pahl (2009) argues that a multimodal lens on children's literacy can reveal and open up new and widened ways to look at children's lives. A multimodal lens can even result in children's activities being considered more relevant and accurate, compared with an analysis being focused on verbal or written language only. Pahl's research further emphasizes how language and multimodal creation of texts become intertwined by communicational activities for children. This is also brought up by Stein (2008) in her studies on children's creation of multimodal practices. Both Stein (2008) and Pahl (2009) argue that multimodal analysis can create a deeper understanding of children's meaning making.

As I described earlier, programming in this chapter can be seen as gender-coded, as foremost a masculine activity and interest, which in turn can be intertwined with the gender norms that exist in preschool in general. It can be argued that the communication that is created in a teaching situation about programming in one way or another contains aspects of gender, since programming is often understood as something masculine. The research interest must be to question this and try to find empirical examples.

In the presentation of examples from the study concepts such as gender norms and gender coded, and also the concept of gender didactics are used. These three concepts are understood as nuances of an understanding of gender as something done through actions, either linguistic or bodily. Gender is about how we "become" girls, boys, women and men and how this partly takes different expressions in different contexts. Everywhere we are, our ways of being and communicating are shaped, so also how we are like girls, boys, women and men (Francis, 2012).

The reason why gender aspects get a lot of attention, both in preschool and in society more generally, could be because it is a linked power imbalance through the ways girls and boys are allowed and expected to be. For example, in preschool, their understanding of how they, as children, and later as school pupils, can be and are expected to be formed. Thereby, norms as well as visible and invisible rules are created about gender which can partly aim to give more influence and power (formal or informal) to a particular group than to another, and partly to mean that certain groups get more influence than others in social context which makes them feel more welcome, more included and more secure. When it comes to learning, this could then mean that some children will feel more included than others, and consequently learn more. This is the reason why gender norms and gender aspects need attention in the educational context in preschools. The question one can ask is whether there are relevant norms in preschools that allow all children to be included and thereby develop and learn, or if some groups are favoured in a way that is not in line with the goals of the curriculum.

3.5 Study Context and Design

The presented study was conducted in the context of a Swedish preschool setting, that is, ECE for ages 1–6. In order to address the research interest, video recordings from teaching sessions at a preschool unit in a mid-size Swedish municipality were analysed. We chose this particular unit, as it has two teachers who were very interested in teaching programming. This can naturally also be argued to lead to potential bias, but since teaching programming systematically, as they do, in early ages is still not very common and lacks a research basis identities, we did not see the teacher selection as a problem. In order to get reliable data, there was a need to find engaged teachers who were committed to work systematically over a longer period of time.

The research has been designed as a case study. According to Jensen and Sandström (2016) case studies should develop and generalise theories, resulting in a so-called *analytical generalisation*. They argue that "an analytical generalisation is based on the ability of one or more concepts to understand or explain events (or activities, processes) in different contexts" (p. 64). In this research, the concepts central to understanding the events and activities found were programming and debugging at preschool level. Jensen and Sandström also point out that complex phenomena that are investigated should be contemporary and understood through concrete events. I see programming as a contemporary phenomenon and I try to deepen the understanding of how programming is a social practice by analysing concrete events. Therefore, the case study design has been appropriate in relation to the aims and research questions in this study and we argue that the results can be analytically generalised.

The data consist of video recordings of teaching sessions with children and a teacher working on programming. Children are engaged in both unplugged activities, such as programming using verbal instructions or cards, and tasks that involved some digital equipment, such as small robots (Blue-Bots) and iPads.

The video material was recorded in the preschool during the school year 2017–2018. The video material consists of 25 sessions of teaching in programming with preschool children, who were four or five years old. The preschool group consisted of around 18 children, but not all were always present. The children participated in the video sequences in smaller groups, ranging from pairs to groups of eight children. All in all, the video material comprised 30 h. One of the members of the research team took care of recording the sequences at the preschool once a month, whereas the preschool teachers, guided by the researcher, recorded the other sequences. The collaboration between the researcher and the teachers was successful. The teachers were instructed to (1) record the videos focusing on the children's activity as close as possible, (2) try to get as many children as possible in the recording and (3) make sure that speech would be audible.

3.5.1 Analysis of the Video Recordings

The analysis was carried out in several steps. First, all video recordings were watched several times, with research interest concerning programming and gender in mind, in order to get an idea of the width of the data. The research team found a number of sequences where gender was featured, and in most of them it was featured briefly through verbal comments. There were also sequences where only one member of the research team (either myself or another member of the team) initially interpreted that gender was playing a role. One of those examples I chose to present here as the first example. The second example presented here concerns a much clearer sequence, almost as a set up where the teachers wanted to think about gender together with the children. With these ideas in mind, I watched some of the video recordings once again, in order to reformulate or reshape ideas if necessary. The selected sequences are examples that could function as representations of the most common gender patterns found in the material. One video recording can, however, never represent another, so with that in mind, the transcription and the gender analysis were done as parallel processes.

3.5.2 Example from a Preschool that Works with Programming

In this chapter, sequences have been highlighted and analysed which, in various ways, actualise gender aspects in teaching. Two research questions were formulated. One was: "How is gender done in teaching about programming?" That question is also useful for preschool teachers to reflect on in relation to their own teaching, being any subject. A follow-up question to it was formulated as: "How can preschool programming be a part of making programming something that is regarded as both feminine and masculine?"

3.5.3 An Ethical Approach in Connection with Research on Children

When children are filmed in their everyday life, it is important to have an ethically well-grounded approach to the video footage, and to the children. In the study presented here, all parents had received detailed information and were asked whether their children may be involved in video recording for research purposes. Most accepted participation, but not all.

In the actual work, this, in cases where the parents have not approved participation, their children have not been involved in the sequences recorded. And since the groups that have been taught almost always have had different compositions, no child has had to feel exposed or visible—neither as filmed nor as un-filmed.

Besides the adults' "yes", the children have of course also been given the opportunity to make their voice heard. As a researcher, I have carefully explained what I am doing and why I film, although it may be abstract for some children. I have exemplified how they can say no to participate, either by saying no, using the stop hand or turning away the body. In the filming I have also been careful in trying to feel the children's bodily expression and in some cases interpreted (wrong or right?) that a child does not want to be filmed.

The preschool teachers in the study have been informed about what the study means, what their part is and that they have the opportunity to choose and opt out of video sequences that they are not comfortable with. It has been an ongoing conversation between me and the teachers about the recordings and the material that has worked well.

3.6 Results of How Gender Is Made in Programming Teaching

In the two examples below, which are taken from teaching situations where a preschool teacher and a group of children together are programming a robot, two overarching themes are highlighted: how the teachers make gender in the teaching and how the robot is made into a "he" in the conversations in the programming. Before the first example is presented, however, I would like to emphasise that the preschool teachers who participated in the study are extremely reflective, thoughtful and inclined to development. They are educated preschool teachers and have worked some years together as colleagues, and have jointly developed their knowledge in the area of programming in preschool. They have clear support from the preschool administration in their municipality and are often invited to hold inspiration meetings and train colleagues at other preschools.

The reason I write this is that, as a reader of a chapter that makes critical analysis of teaching, it can be easy to believe and think that the teachers who are described do not do a good job. But they do! They are also willing to learn, and this can be seen in the second example where they themselves have initiated and tried to get an idea of the children's gender norms.

3.6.1 Preschool Teachers Do Gender in Teaching

In the following examples, the focus is directed toward the teachers and their ways of doing gender. The purpose is to exemplify small linguistic and communicative actions that, if they happen too often and too continuously, can result in girls not feeling included in the programming teaching. It can also lead to them choosing to self-exclude themselves, that is, directly or indirectly, thinking that programming is not something for them. Doing gender in practice in preschool and in, for example, programming teaching is seldom about a clear exclusion of either girls or boys, but about small linguistic or communicative actions where the girls and/or the boys, or certain groups of girls or boys, are not included in the teaching in the same way as the others.

3.6.1.1 "No, We Should not Take the Carpet Now"

In the programming lesson held this day, the children's group, comprising five children, were very happy. They wanted to try every possible way to use the robot, also called the Blue-Bot. The group worked with the Blue-Bot for about 15 min together with preschool teacher Linda. Linda, who was used to working with this group of children, had planned a set-up that meant that the children would have to test the Blue-Bot and program it so that it moved from location A to location B. She showed that on Blue-Bot's "back" there were arrows that pointed forward, backwards, turn left, turn right, pause and delete. Each child then got to test, measure the length of the Blue-Bot's steps, think along with the other children and talk about how the move would take place in the best way.

Thereafter, the children were allowed to try themselves without instructions from the preschool teacher and after the formal teaching and testing was over, most of them continued on their own. All the time Linda was actively present to make sure that the Blue-Bot was not turned into a toy. The teachers had reflected a lot on the fact that they did not want the robot to be an entertaining thing for the children, but that it would have the character of being something that was only used in teaching and learning situations.

During the test, one of the children, let's call her Natalie, saw a plastic mat with boxes of different colours that Linda had taken with her and which she had had an idea of using in connection to the teaching. Linda, however, had not used the mat, but Natalie was curious about the mat and asked Linda if she could try it. Linda then answered clearly, and with quite a certain voice, that they would not use the mat. In addition, she directed her body against Natalie as to clarify her negative answer, which Natalie could have understood as being excluded. When Natalie asked again, she received the same answer: No, the mat would not come up now. Shortly thereafter, some of the boys went and took the mat and spread it out on the floor. Neither Linda nor anyone else said anything about this, but the mat became part of the continued testing. For Natalie's part, it meant that she eventually had to test the mat and Blue-Bot, as she had wanted from the beginning. The dilemma of this situation was that she had asked for permission and got a no, while the boys took the mat without asking and without being stopped. The signals this situation sends can be interpreted from a gender perspective, where boys are not told when they do certain things, while girls can risk getting a no if they ask. Is it then better for children to just do as they wish or should they ask first?

3.6.1.2 The Robot Is a "He"?

The second example is a situation in another programming teaching sequence in the current preschool that focused on the children starting an understanding of debugging as a phenomenon in programming. Debugging is a central part of learning programming. It requires analysis ability and creative thinking in order to solve the "bug". Debugging can also be a way to develop children's analytical abilities in general.

In the teaching situation, two boys sat with preschool teachers Linda and Anna. Together they did the activity "find five errors" with a regular picture and talked about what it was like to find errors and search for errors. They also talked about the concept of "bug" and that it was an English word which had several meanings.

After that, Anna took the Blue-Bot for the boys, so they could practice debugging according to instructions they would receive from Linda and Anna. To test gender and test their own language about gender, Anna had put false eyelashes on one of the Blue-Bot's "eyes".

When Anna showed the boys the Blue-Bots, without saying anything about the eyelashes, the boys were silenced. Then they directed their bodies and glanced at the Blue-Bot that did not have eyelashes and the following dialogue took place:

Oskar: I want the boy.

Linus: But, I want the boy.

Anna: Why do you think it's a boy?… Why is it a boy?

[Silence while both are watching both robots.]

Linus: And why is that a girl?

Anna: Why it?

[Linus takes the robot with eyelashes and turns it against him.]

Linus: But, oh, how cute she is!

Linda: But why is it cute?

Anna: How can you … How do you know that it is a girl and a boy?

Oskar: It's cause they have …

[Oskar points with his fingers against his own eyes.]

Linda: What's that?

[Silence]

Linda: Do you mean eyelashes?

[Linda looks at Oskar.]

Anna: They here? [Pointing to the eyelashes.] But boys also have eyelashes.

Linus: Yes. These.

Anna: You also have such eyelashes.

[Anna points to Linus eyelashes]

Oskar: Yes, don't want to have that one.

[Oskar points to the "girl robot".]

Anna: You can choose which one you want to use.

[Both boys point to or grasp the one without eyelashes. However, Linus looks at the other one when Anna removes it from the table]

Linda and Anna later told me that they did not expect the boys to react so much and so clearly to the Blue-Bot's eyelashes. They were both astonished and somewhat distressed that the "test" so clearly showed that the boys categorized the bots, as well as perhaps also themselves and other children based on gender, and that they added some signifiers to this gender categorization. The boys' preferences regarding gender were also quite clear, although Linus expressed the categorization more clearly than Oskar, especially through the connection to "cute". Furthermore, Linus was not entirely convinced that he only wanted the "boy robot", but his gaze also followed "the girl robot" when Anna removed it from the table. Oskar was much quieter than Linus, but with the help of pointers and his body position, expressed more clearly that "the boy robot" was his preference.

The boys' reflections on the significance of the eyelashes for doing gender were enhanced when Linda and Anna later, in another group with some other children, tried to give them only the Blue-Bot with eyelashes. Some of the boys then said that they did not want to use it at all and asked for the "usual" Blue-Bot. The conclusion that Linda and Anna drew from this was that the boys did not want the robot with the eyelashes, while the girls could have both that one and the one without eyelashes.

This trend is in line with other research that points to girls being able to relate as much to, for example, girls and boys in children's books, while boys have a clearer preference for boy characters. This can in turn be related to what is highlighted in a governmental report about masculinity related to schooling (SOU, 2010:53) where it appears that one of the characteristics that exist regarding how a "real boy" is expected to be (there is of course no such "list", but tendencies) including that he should distance himself from the feminine and feminine connotations in order to avoid being perceived as an unreal boy. This can be important knowledge for preschool teachers, while at the same time problematising gender, and also needing to be aware of the nuances in gender identity.

3.7 Conclusion

The question that one can of course, and should, ask after having read so far is: "What sort of conclusions can one draw from two individual examples in this case study?" The answer is likely, not so great, if any at all. However, these can function as examples which together with a large amount of other research (see Blaise, 2005; Dolk, 2013; Eidevald, 2009; Hellman, 2010; Paechter, 2010) show how gender patterns in preschools are created and established. They can exemplify and again emphasise that gender is done in the preschool and that what is done may be seen as small things, but that, lined up next to each other, they form a certain kind of norm and pattern of behaviour for the children. In order for these patterns not to take place and be established, there must be adults who question and challenge the sometimes one-sided image of women and men that the children can otherwise risk being brought up with. The risk is then that children's talent and interests are diminished by adults and gender norms.

This becomes even more important when it comes to teaching in the preschool in a Swedish context, which will be even more in line with the new curriculum (Läroplan för förskolan [Lpfö 18], 2018). For example, teaching in different thematic entities, such as different topics of digital, technical and mathematical contexts in preschool, will have to become more common. Today there are tendencies that STEM knowledge would be based on less subjective "opinions" and thus are more truthful. This is of course not true. The knowledge that exists in STEM is partly developed in certain kinds of processes, and partly it is chosen to be regarded as important knowledge of people who have probably been gender-marked by their time.

This chapter can remind preschool teachers and researchers that gender is being done in all parts of the preschool, also when it comes to developing computational thinking and implementing programming teaching. Perhaps the text can lead to gender-didactic reasoning and reflections that can have girls and boys included on equal terms. Furthermore, it could give the teachers tools that help them manage what boys and girls choose and that they seem to value girls and boys differently. To counter this, they need gender-didactic tools and practice in managing conversations with children about gender.

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Chapter 4
Mathematical Signs and Their Cultural Transmission in Pretend Play

Maulfry Worthington

Abstract Mathematics is a critical aspect of early childhood curricula and integral to competency in all STEM subjects. Developed historically, the abstract symbolic language of mathematics is a powerful cultural phenomenon. Using a genetic approach to research the beginning mathematical inscriptions of 3–4-year-olds has highlighted their *meaning-based symbol use* as children move towards the formal, "higher psychological functions" (Vygotsky, 1978, p. 46). Underpinned by Vygotsky's socio-cultural and social-semiotic theories, this chapter considers *from whom* and *how* young children learn the mathematical signs of the established cultural system of mathematics. It investigates intertextuality and modes of cultural transmission, the *social learning mechanisms* of imitation and emulation whereby teachers, other adults and children transmit cultural knowledge. The findings show the potential of rich pretend play for learning including peer-to-peer *natural pedagogy*, highlighting the importance of an effective early learning culture and underscoring the extent to which social learning is paramount for mathematics.

4.1 Introduction

Young children exhibit a "clear readiness to engage in STEM learning in early life" (McClure et al., 2017, p. 4), and in the early years STEM subjects (science, technology, engineering and mathematics) "are deeply interconnected and can be taught effectively in concert, with science and mathematics as anchors" (p. 17). Learning should be "*developmentally informed*" (p. 5, emphasis added), McClure et al. recommending "real-world learning" that connects with children's out of school experiences (p. 55). Clements and Sarama (2016) argue that when provided with suitable opportunities, young children "possess a surprisingly broad, complex, and

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sophisticated informal knowledge of math" (p. 77). Hoyles, Reiss and Tough (2011) also underscore the importance of research in supporting STEM subjects.[1]

For McClure et al. (2017) "the false dichotomy […] between children's play and their cognitive, social, intellectual, and academic development" need to be erased (p. 12), Clements and Sarama (2014) asserting, "of course children should play. But this does not mean they should not learn, and even play, with mathematics".[2] Whilst there will be some direct teaching, free play experiences form the intuitive, implicit conceptual *foundation* for later mathematics (Hewes, 2014). Later, children represent and elaborate these ideas—creating models of an everyday activity with mathematical objects, such as numbers and shapes; mathematical actions, such as counting or transforming shapes; and their structural relationships. This is the process of *mathematisation* (Clements & Sarama, 2014).

The findings from these studies are of particular relevance for this chapter. Playing an intrinsic role in developing abstract thinking, the visual signs and representations of mathematics mediate understanding and enable children to communicate ideas, yet many find abstract symbols challenging (Carruthers & Worthington, 2006; Hughes, 1986; Poland, 2007; Worthington, Dobber & van Oers, 2019).[3] The relationship between young children's own signs and texts and the formal symbolic language of mathematics is poorly understood, and whilst in research there is a growing understanding of children's ability to use their own marks and signs to represent their thinking, globally, children's difficulties with standard symbols are seldom acknowledged in governmental guidance or in early childhood curricula for the 2–7-year-old phase.[4]

Inappropriately premature expectations that young children should *begin* with formal signs and procedures without connecting them to their existing understandings can cause significant problems for their understanding of mathematics in the present and later in school (Carruthers & Worthington, 2006; Ernest, 2005; Ewers-Rogers, 2002; Ferrari, 2003; Ginsberg, 1977; Gravemeijer, 1999; Hiebert, 1984; Hughes, 1986; Poland, van Oers & Terwel, 2009; van Oers, 2010), and have been found to induce alienation towards the subject of mathematics (van Oers, 2012, p. 137; Williams, 2016).

In his seminal text Martin Hughes (1986) argued, "children need to develop links—*or ways of translating*—between the new language and their own concrete

[1]Involving all staff and the headteacher and drawing on their own and others' research, the nursery school in which data were gathered for this research places considerable emphasis on research-based practice.

[2]In England, a growing threat to young children's meaningful learning is the increasing "schoolification" of teaching for children up to six years of age, including the growth of "Teaching for Mastery" for mathematics (from Singapore and Shanghai), which is increasingly influencing early years practice on England (see for example, Boylan, 2019; Worthington 2020).

[3]The visual signs and representations of mathematics are analogous with the terms *inscriptions*, *notations*, *symbolic/psychological tools, emergent models* and (from Carruthers & Worthington, 2006) *children's mathematical graphics.*

[4]The author acknowledges Vygotsky's designation of early childhood as 2–7 years, whereas in England the early years' phase is classified as birth to 5 years.

knowledge" (p. 51, emphasis in the original), proposing that teachers, "*build on children's own strategies*" and "*respect their invented symbolism*" (p. 176/177, emphasis in the original).[5] Taking a genetic approach and drawing on recent qualitative research from an inner-city nursery school in south-west England, this chapter considers the people from whom young children learn the signs and representations of mathematics and *how* they learn them.

4.2 Theoretical Underpinning

4.2.1 Social Learning, Cultural Learning

Vygotsky proposed two "lines" for the genesis of human mental activity: the natural line (for elementary mental functions) and the social or cultural line (for the higher mental functions)" (Bartolini Bussi & Mariotti, 2008, p. 749).[6] The word "culture" originates from the fifteenth century Latin *cultūra,* meaning *cultivation* and *growing,* and, by the sixteenth century its sense encompassed *cultivation of the soil*, from which cultivation of the mind, and culture as the social behaviours, customs and beliefs of human societies took hold. Together the research explored in this chapter highlights the importance of the *culture* of early childhood settings, and of young children's free and spontaneous pretend play in developing a rich diversity of graphical inscriptions. Social learning and the transmission of knowledge of mathematical signs and texts are integral to this. Vygotksy (1981) highlighted social interaction originating in cultural activity as having a fundamental role in meaning making and in developing cognition:

> Any higher function was external (and) social before it was internal… We can formulate the general genetic law of cultural development in the following way: Any function in the child's cultural development appears twice … first between people as an intermental category, and then within the child as an intramental category… Social relations or relations among people genetically underlie all higher functions. (p. 163)

Van Schaik and Burkart (2011) explain *social learning* as "learning by observation of, or interaction with, another" (p. 1009). Not only do the young of various species "actually show a preference for social learning over individual exploration… [but] individuals with more opportunities for social learning systematically acquire a larger set of learned skills and also become better asocial learners" (p. 1010).

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[5]Both teachers and early years' practitioners work in the nursery school, but for brevity the word "teacher" is used throughout.

[6]Vygotsky's "genetic" approach (1978) is developmental, "a historical perspective" that begins with the origins of development in order to understand its present "… *To study something historically means to study it in the process of change"* (pp. 64–65, emphasis in the original).

4.2.2 The Importance of Signs

Vygotsky (1978) argued, "*Sign-using activity in children is neither simply invented nor passed down by adults*… [it becomes] one only after a series of *qualitative* transformations". Children's behaviour is born from interweaving elementary processes of "biological origin", and the "higher psychological functions, of sociological origin" (p. 46, emphasis in the original).

Young children use graphical signs to make and communicate meanings and to solve problems. Bartolini Bussi and Mariotti (2008) emphasise the "move from personal sense" to "culturally determined mathematical signs *is produced by cultural development*" (p. 756–253, emphasis added). Dijk, van Oers and Terwel (2004) stress that semiotic activity is "the cognitive activity of reflecting on the relationships between sign and meaning, or more particularly, reflecting on the mutual relationship between the change of signs and the change of meaning" (p. 74). For Carpay and van Oers (1999) "thinking and making sense (in society as well as in schools) has to be conceived of as *sociosemiotic process* in which oral and written *texts*… constantly interact in order to bring about improved texts on the part of the interlocutors" (p. 303).

4.2.3 Play

For Vygotsky, pretend play is fundamental (1967): it represents a sophisticated and important form of social activity: it fulfils the "highest level" of learning (p. 9) and provides many opportunities for meaningful social learning. Vygotsky understood the relationship between an object and its imagined purpose as a pivotal role: for example, when using a wooden brick as a phone the child has provided the brick with a new meaning (first-order symbolism). Similarly children come to understand that mathematical signs (second-order symbolism) can be used to signify new meanings. van Oers (2005) argues, "the potentials of imagination" are "the emergence of abstract and divergent thinking" (p. 15).

Vygotsky (1967) acknowledged pretend play as "a leading source of development in the preschool years" (p. 1), explaining "the child moves forward essentially through play activity" (p. 8). Vygotsky viewed play as a cognitive process, the imaginary situation containing "rules of behaviour" which arise from children's play narratives, from the artefacts, behaviours, speech and actions they employ in their pretend play episodes. For Vygotsky (1978) "make-believe play, drawing and writing can be viewed as an essentially unified process" (p. 116), and can provide meaningful opportunities for the development of everyday concepts for children up to seven years of age (p. 238).

Children's engagement in pretend play is interpreted by Hedges, Cullen and Jordan (2011) as "spontaneous, self-motivated play, discussions, enquiry, and or investigations that derive from their social and cultural experiences" (p. 187), arising from their personal interests (Worthington, 2018). Social pretend play offers potentially rich contexts that "situate" learning and allows children to explore their existing cultural knowledge of mathematics, their "funds of knowledge" (Moll, Amanti, Neff & Gonzales, 1992; Worthington & van Oers, 2016, p. 54). Researchers including Aubrey (1997) and Carruthers (1997) have highlighted young children's home cultural knowledge, yet in educational settings there remains "such a mystique about maths as a cultural activity" (Munn & Kleinberg, 2003, p. 109, cited in Worthington & van Oers, 2016, p. 51).

Valuing children's early cultural knowledge and understandings, we should expect to find examples of their mathematical explorations in their pretend play; however, Gifford (2005) found a significant lack of evidence of this (p. 2). Could it be the nature of the children's play in educational settings? Play scholars have identified "a widespread lack of understanding of play, which results in pretend play that lacks clear connections to the children's personal experiences of life" (e.g. Rogers, 2010; Brooker, 2011). Consequently, concepts are "*conceptually disembedded* from the practices and the imaginary situation being played out by the children" (Fleer, 2010, p. 75, italics in the original, cited in Worthington & van Oers, 2016, p. 64).

Rogers and Evans (2008) highlight the tension created in adult-planned play "between children's "natural and powerful propensity to play in ways that transform and find new meanings… so that requirements in literacy and numeracy can be met" (p. 37). "This highlights practice common in most of the world where adults choose, plan and resource themed role play areas, revealing adults' perceptions of children's interests, rather than children's authentic and immediate interests that have personal cultural meaning" (Worthington & van Oers, 2016 p. 52). These tensions are reflected by Munn and Kleinberg (2003), who maintain that children need to learn the cultural rules [of mathematics] concerning "how to use a system, and what its role is in our culture" arguing, "these cultural rules are possibly the most important things that children learn": without understanding them children "risk becoming stranded in a sea of meaningless activity" (p. 51/53).

The mathematics explored in the research and in this chapter is neither "play-based", nor is it through adult-planned play with mathematical expectations or goals. Rather than teachers planning for pretend play (and finding little evidence of mathematics), the findings of Worthington and van Oers's (2016) study points to the importance of *genuinely free* pretend play in which children *spontaneously* initiate and shape their pretence, freely engaging in and communicating their thinking about and understandings of mathematics through dialogue and their mathematical inscriptions. In this study more that 44% of the children's pretend play episodes included evidence of mathematical explorations (p. 59). When pretend play is well understood and children have meaningful opportunities in which to engage in pretence, they will freely explore all aspects of their cultural knowledge from their daily lives, their play narratives including all "five major mathematical topics" of the mathematics curriculum, "number and arithmetic, geometry, measurement, patterning and algebraic thinking, and data and graphing" (Sarama & Clements, 2008, p. 67, cited in Worthington et al., 2019).

Pretend play has "a sustained role…in cognitive development" (Harris, 2007, p. 223) and in the development of cultural knowledge (Riojas-Cortéz, 2000): according to (Boyette, 2016) it creates a *culturally constructed interactional niche,* referring to the ecological, material and cultural contexts "in which social interactions take place" (p. 161). However, whilst adults may refer to certain behaviours as *pretend play*, "mathematical learning does *not* just occur incidentally in play situations" (Gasteiger, 2015, p. 260), and unless children's actions "are intentionally and reflectively carried out, we cannot say that children perform mathematical action" (van Oers, 2010, p. 28).

4.3 Approaches to Children's Mathematical Inscriptions

A number of researchers have investigated the teaching and learning of mathematical signs in early childhood, including the Dutch *Realistic Mathematics Education* (RME) (e.g. van den Heuvel-Panhuizen, 2003), and also from the Netherlands, *schematising* (e.g. van Oers, 2010). A third approach is *children's mathematical graphics* (focusing on children's communication of *meaning-based symbols*), originating in England. All three approaches are intended to assist children in bridging "between the concrete practical thinking of young children" and subsequent symbolical thinking (Poland et al., 2009, p. 307). Aiming to reform the ways in which mathematical inscriptions are traditionally taught, these approaches have developed alternative conceptions, although they differ in the ways in which teachers introduce inscriptions and support children's understandings.

4.3.1 Children's Mathematics

From the early 1990s, Worthington and Carruthers developed *children's mathematical graphics*, an instructional design that *begins* with children's own informal marks, symbols and procedures supported by adults. It aims to ensure the establishment of strong and effective beginnings, gradually building on the children's informal marks, drawings and signs they use to communicate their thinking, to encompass abstract signs and ways of representing. In comparison to formal, directly taught signs and symbols, children's *own* marks and signs (made in contexts that are mathematical) reveal a considerable amount about their understandings of sign-use. Carruthers and Worthington's research has focused on children's *own* mathematics and the *processes* of representing mathematical ideas. Their signs differ from those older children and adults use; they are personal and often intuitive and mathematise over time.

Investigating young children's personal and freely made mathematical inscriptions, Carruthers and Worthington charted their development from birth to eight years (e.g. Carruthers & Worthington, 2005). They developed a bi-directional model to indicate how the gap described by Hughes (1986) might be "bridged" (p. 80), proposing that using their own marks and signs "and making their own meaning—shared, discussed and negotiated within a community of learners—enables children to become bi-numerate", to move between their informal mathematical beginnings and the abstract symbolic graphical language of "school" mathematics (p. 106).

Worthington et al. (2019) contend that this approach rests on an effective *culture* of the early childhood setting; it is the culture that determines the opportunities children have to engage in rich play episodes, to explore and develop their thinking and to make mathematical meanings. In the nursery school that is the focus of the research discussed in this chapter, the headteacher and staff had developed a democratic culture in which adults' value and support children's self-initiated ideas and means of expression. Children freely initiate their play and spontaneously originate mathematical ideas within the context of their play narratives, and within open, adult-led small groups. Adults value and understand pretend play well, and "as more knowledgeable others, adults notice and recognise children's language and graphics as mathematical" (Worthington et al., 2019).

4.3.2 The Genesis of Mathematical Semiosis

In recent years the author's research has focused particularly on young children's mathematical *beginnings* through four inter-related research studies, first into the mathematics they choose to explore (Worthington & van Oers, 2016), and secondly their use of social literacies at home and in the nursery (Worthington & van Oers, 2017). These studies led to an investigation of children's development of mathematical abstraction in the nursery (Worthington, Dobber & van Oers, submitted). A fourth study (Worthington, Dobber & van Oers, submitted) examined the role of intertextuality in children's developing mathematisation, further developing Carruthers and Worthington's 2006 *bi-numeracy model* to integrate Tomasello's (1999) "ratchet" and indicating how young children's beginning marks and signs mathematise over time as they move towards the abstract symbolic language of mathematics (Worthington et al., submitted). These four studies investigated the children's mathematics and sign use within their spontaneous pretend play.

4.3.3 Intertextuality

One way in which we learn from others' speech or graphical inscriptions is through *intertextuality* or "multivoicedness" (Wertsch, 1991), which draws on Bakhtin's (1981) perspective of "utterances" and reflects others' speech through "ventriloquation". Worthington (2005) explains in the children's graphical examples that there is also an element of many "voices" that reveal something of their "pre-history" (p. 79). Children appropriate and adapt signs they see others use, the signs becoming their own (Bakhtin, 1981) "when they *populate* them with their *own intention*, their *own* *accent"*, adapting them "to their own semantic and expressive intention" (p. 293) and "making them available as artefacts for their social group" (Worthington, 2009, p. 43). "The word in language is half someone else's" (Bakhtin, 1981, p. 293), and as we borrow and share the graphical signs we use, we create a chain of signs. Following Bakhtin, Kristeva (1980) sees each text as an intertext in a succession of texts already written or yet to be written, texts become 'a permutation of texts", (p. 36), connected by shared codes (signs).

In a recent study, Worthington et al. (submitted) investigated children's inscriptions for evidence of their intertextual sign use,

> From their own and others' utterances (e.g., word combinations, drawings, signs), young children appear to subconsciously consider those features that have the potential to effectively communicate their current thinking, sometimes using signs intertextually… From their early attempts at communicating, children weave different (self-made or adopted) signs and symbols together, rendering their expressions a text-like character (Submitted).

Analysis of the children's inscriptions by Worthington et al. (submitted), showed that, "some signs moved between individuals' texts, [and were] also borrowed from and woven together by others, including those modelled by the teacher" identifying a small number of graphical signs the children frequently used (dots, ticks, crosses, letters and numerals), which they included in their drawings, letter writing, environmental signage, paper models and play. Whereas the children sometimes used scribble-marks to signify their meanings, they had also clearly begun to explore the differences and roles of abstract signs, as the first two examples (Figs. 4.1 and 4.2) show.

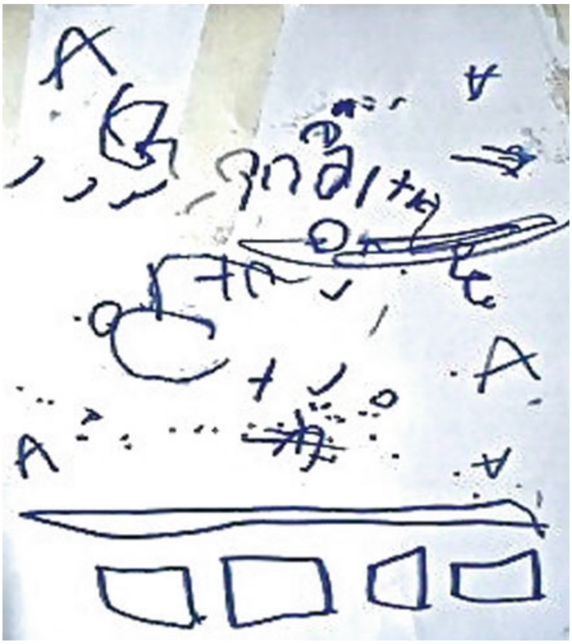

Fig. 4.1 Ayaan's "television"

> When playing "Mums and babies" Ayaan decided that her baby needed a television. Rather than drawing a "picture", Ayaan wrote several letter-like signs, dots and rectangles, and included several ticks and a cross (Fig. 4.1).

Together with the capital letter "A" of her name, the ticks and cross were the first formal signs Ayaan had used. Crosses are abstract symbols children use to signify both similar and different meanings (Worthington, 2009) and are acknowledged by Bartolini Bussi and Mariotti (2008) as a "foundational" or "pivot sign" (p. 757) (Worthington et al. submitted). Ayaan's first language is Somali and at this time her aunt was teaching her Arabic writing at home. Ayaan's use of the letter "A" is likely to reflect her confidence in her knowledge of the first letter of her name (using the Roman alphabet). It's clear that in this example Ayaan has included a combination of using known letters and letter-like signs (suggesting "writing"), the rectangles suggesting the shape of a television. It is not known why she used ticks or a cross in this example, although young children do not always explain their graphics.

In another example:

> Oliver (who was missing his Mum) said, "*I'm going to write my mum a letter, to pick me up now*". He used dots, zigzag writing-like lines, a sign like a tick and letters "o", "s" and a capital letter "I". Oliver drew on his existing lexicon of signs, including several letters he used when signing his name (Fig. 4.2).

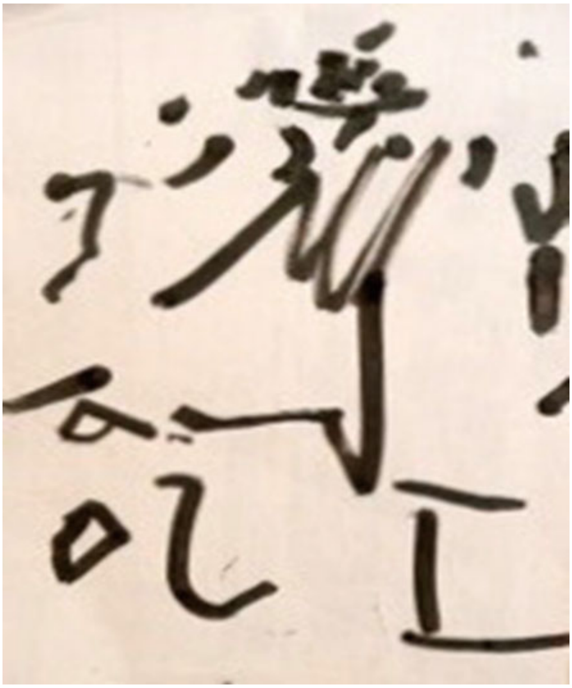

Fig. 4.2 Oliver's letter to his mum

On another occasion Oliver drew numerous dots on a whiteboard to represent "*lots of* baddies" his many dots representing a large, *uncounted quantity.*[7] Figure 4.5 (in the proofs this is p. 16) shows also Oliver's car-park entry sign in which he included almost identical signs as those he used in the letter he wrote to his mum. These three texts (a letter to his mum, a representation of numerous "baddies" and an environmental sign) exemplify the intertextual nature of some of Oliver's signs across several of his own texts, which also related to the dots and ticks in Ayaan's "television". At this point they show that the children have drawn on different symbol systems (e.g. dots, abstract symbols such as ticks and crosses and drawings), their endeavours helping to determine which symbol system best suits their communicative purpose.

4.3.4 Letters and Numerals

Throughout the year Elizabeth was fascinated with letters and numerals and her texts often featured these, and like Shereen, she freely and spontaneously used almost all letters of the alphabet (upper and lower case) and numerals 1–10, others building on them intertextually. Her favourite number was "100" and on several occasions she proudly showed others that she could write this. Elizabeth was especially interested in the *appearance* of letters and numbers, for instance commenting, "*5 is like a 2 backwards*." She was perplexed that the numerals that appeared on a number line in Urdu were so different from the Roman (Latin) script, and pointing to the Urdu numeral for five observed, "these aren't numbers, that one look like a heart!"[8]

Both Elizabeth and Shereen used letters and numerals in diverse contexts for various purposes and during the year other children picked up on this, some including letters and numerals in their drawings at home, and others freely doing so in the nursery. David wrote the numeral "3" (his age) on the path in the nursery garden and Tiyanni wrote her house number:

> Playing in the garden shelter with her friends Tiyanni announced "*It's our house*" and Hugo (her teacher) asked if it had a number? Writing her house number on the wall in chalk along with some scribble-marks, Tiyanni pointed to the large, almost enclosed circle on the right of the photo, *"that's the number 8 and the other number's 9"* (Fig. 4.3).

In similar ways the children drew on signs and their functions modelled by their teacher. For example, Emma had modelled the use of tallies within a context that was meaningful to the children, and following this,

> In the forest one day, the children arrived at a curious shelter with a wooden pallet in its entrance, and David wondered if an elephant lived there? Shereen watched as the children went inside, then drawing an elephant on her hand she wrote tally marks beneath it as she counted each child going into a shelter, finally counting the marks on her hand up to 10.

[7] See Carruthers and Worthington's taxonomy (2006).

[8] 'Five' written in Urdu: ۵.

Fig. 4.3 Tiyanni's house number "89"

These signs and others moved within individual's texts and between several children. Carpay and van Oers (1999) explain that from a Vygotskian perspective "learning activity depends strongly on *intertextuality*" (p. 303, emphasis in the original), and through employing a range of signs children's intertextuality "contributes to symbolic diversity, providing multiple perspectives of signs and enriching children's expanding sign-lexicons with the help of adults' signs and texts" (Worthington et al. submitted).

4.4 Social Learning and the Transmission of Culture

4.4.1 Social Learning Mechanisms

In recent years and following Cavalli Sforza and Feldman's (1981) research in which they identified *specific modes* of cultural transmission, research has focused on various social learning mechanisms that support children's learning. These modes include *vertical* transmission (from parent to child), *oblique* transmission (other adults to child/children) and *horizontal* transmission (among peers) and include imitation and emulation, learning strategies that advance children's acquisition of the cultural knowledge and practices of their society.

4.4.2 *Learning from Adults*

4.4.2.1 Learning from Parents

Young children develop their cultural knowledge at home through culturally valued and purposeful activities, often with a parent. This *vertical transmission* of knowledge may be both direct and incidental, imparted informally within everyday family practices.[9] Worthington and van Oers (2016) found that parents' everyday activities influenced children's play narratives and concepts, evidence of their cultural knowledge from home visible in their pretend play. Unsurprisingly, Csibra and Gergely (2006) argue that among humans "vertical transmission seems to be the dominant mode of diffusion of cultural traits".

4.4.2.2 Learning from Teachers and Other Adults

This mode of cultural transmission is known as *oblique* (Csibra & Gergely, 2011). From an educational perspective the question of the transmission of aspects of a culture judged to be important for that culture such as mathematics is widely acknowledged to be largely the business of schools and has an increasing role in the education of older children.

The practice of direct and systematic teaching is common throughout structured education systems, and even for the youngest children it often constitutes at least a part of the child's experience. However, researchers have identified a problem with *oblique* (e.g. teacher to child/children) transmission, in that in regarding adults as more knowledgeable, children *overimitate* without questioning whether what they have seen or heard matches their own understandings or seems reasonable.[10] Following Bonawitz et al. (2011), Tomasello (2016) observes that counterintuitively, children understand direct teaching, "as THE way, to do it—to the point that they ignore other possible ways" (p. 4, emphasis in the original). Empirical evidence has shown this to cause significant problems in mathematics, children faithfully copying examples given by their teacher with only superficial understanding and often subsequently unable to then use them in new situations.[11]

[9] Such experiences include practical activity in which mathematics is to the fore, and oral and graphical communications.

[10] Whiten (2013, p. 150) refers to overimitation as "overconformity".

[11] However, Carruthers and Worthington (2006) identified an effective means of teacher-modelling that avoids children directly imitating or copying. Rather than transmitting signs directly, teachers frequently model graphical signs in contexts that are personally meaningful to the children throughout the week. They understand that over time these new signs become part of children's lexicons of cultural (psychological) signs. Teachers do not require children to immediately use these signs.

4.4.3 Social Learning Through Direct Interaction

4.4.3.1 Imitation

Specific (and often intuitive) interactions between two or more children within social contexts such as pretend play appear to support a demonstration or pedagogical stance by one peer, and an imitation or *emulation* of actions and behaviours by the other. Hewlett (2016) defines *imitation* as when a child copies "the actions of another in order to obtain the same effects" (p. 8).

Tomasello (1999) explains that imitative learning (with some guidance from adults) occurs as, "a dialectical process over time", enabling children to represent quantities, solve problems, collect and represent data and aspects of measurement in ways they understand (p. 39), creating "solidarity" with others in a group" (Tomasello, 2010, p. 209) between children who are likely to intuitively coordinate their signs and texts with their peers or adults (Worthington et al., submitted).

The following example is of one child imitating another's signs and representations and exploring their thinking about subtraction. Shereen had been playing cafés and on this day decided to represent some transactions on a child-height whiteboard. David was nearby, his proximity, Shereen's decision to involve him and her use of his name creating ostensive signals and resulting in David's *intention-reading*. Tomasello (2005) explains, "joint attention facilitates *intention-reading* in which individuals focus on others" activity and speech, helping determine how they might contribute to the joint activity. *Intention-reading* is the ability to discern another's intentions in a shared social context (p. 5, 6).

> Pointing to the two figures she had drawn on the right of the board, Shereen explained, "*This is me. This is my Daddy at the café*". She drew a flower and a heart above them, followed by five cakes on the left.[12] Shereen asked David "*You like some cake?*" and following his affirmation, she then rubbed out one cake to show it had been sold. Repeating the same question to her teacher, when Emma also replied "*yes*" Shereen rubbed out another cake remarking "*three left"* (Fig. 4.4).

In this instance Shereen's action of rubbing-out served as the operand for subtracting cakes, and suggested its function. "Reading" Shereen's intentions David decided to create his own graphical text of a café:

> Drawing himself and Shereen at the café, David made small marks, and pointing to them explained "*two cakes, coffees, hot coffees, cold coffees, crisps"*. He asked Shereen to "visit" his café and she gave him an order for one cake and a cold coffee. Rubbing out items to signify their removal David said, *"here you go. I have to rub them away now 'cos they're gone from the café*".

Exploring calculations was unexpected for such young children but the meaningful components of their calculations and the processes they used for subtraction

[12] It was unclear to what the "14" at the top referred. The flower and the heart appeared unconnected to Shereen's calculation.

Fig. 4.4 Shereen's subtraction

highlights children's innovative early strategies for "written" calculations (Worthington et al., 2019). The children's graphical signs have **combinatorical** potential, so that when integrated into a text (as here), together they signify something new. Worthington et al. observe "whilst exploring calculation was unexpected for such a young child, Shereen's combination of meaningful elements highlights children's innovative early strategies for *written* calculations" (2019). van Oers (2001) emphasises,

> individual inventions… are seen as social products that may develop into still higher levels of abstraction and constantly feed back into the community and foster the development of the community as well. As such, the individual and the community co-develop.

4.4.3.2 Emulation and Natural Pedagogy

Csibra and Gergely (2011) identified *natural pedagogy* (peer-to-peer pedagogy), a universal mechanism that constitutes a human evolutionary adaptation that is dependent on communication within social learning contexts. They suggest, "the most obvious beneficiaries [of natural pedagogy] are children, who have to acquire the technological, social, conventional and institutional knowledge that are necessary for survival in our culture" (p. 1150). *Emulation* is understood as when "the child observes a particular effect on an object when someone interacts with it. The child is motivated to reproduce the effect *but uses her/his own methodology to do so*" (Hewlett, 2016, p. 8, emphasis added).

According to Want and Harris (2002), "when children are shown the solution to a novel task and can detect and understand the relevant affordances, the solution can be emulated… intuitively, emulation offers a highly flexible form of knowledge" (p. 5).

Emulation seems to be particularly powerful when combined with natural pedagogy, where an individual uses cues such as pointing or calling their friend's name "to draw attention to important aspects of a skill or knowledge" (Hewlett, 2016, p. 8).

Csibra and Gergely (2011) found that infants are sensitive to others' ostensive communicative gestures and "prepared to identify and interpret others' actions as communicative acts that are specifically addressed to them" (p. 1150), indicting the other "is about to manifest 'for' them some significant aspect of cultural knowledge that will be new and relevant and that, therefore, should be fast-learned" (Gergely & Csibra 2007, p. 250). Csibra and Gergely (2009) raise the question that behaviours inherent in peer-to-peer pedagogy share "suggestive similarities" with pretend play (p. 151).

> … if children are psychologically prepared to seek out cultural information, we might expect them not to wait upon its transmission by pedagogically inclined adults. Rather, we can expect children to take their apprenticeship into their own hands—at least when presented with suitable opportunities (Legare & Harris, 2016, p. 636).

Worthington et al. (2019) also found that in their interactions with peers, the children "sometimes use ostensive signals to draw attention to and help clarify their intentions" (e.g. holding up their graphics to command attention, or pointing combined with declarative statements). The following example highlights the *natural pedagogy* arising within two boys' pretend play narrative.

Isaac was very interested and knowledgeable about many technologies and security, and had recently visited a city car park with his dad, where they had to use an electronic card-reader to gain entry. Following this Isaac explored his ideas about access to car parks in his pretend play with Oliver:

> Using scribble-marks Isaac made a sign to guide drivers, explaining, *"This says, "Swipe here with your special code card"*. Then adding further marks he explained, *"this is the bell if you don't have a sticker and someone can let you in. It says, "Press here". This is for lorries and deliveries - it opens automatically - it's a camera"*.

In Oliver's learning diary his teacher wrote, "*Oliver watches and waits before deciding to participate*", appearing to determine Isaac's intentions before he contributed to their play. Oliver had not shared Isaac's experience of visiting the real car park, but his ability to discern Isaac's intentions enabled him to decide how he might contribute to their joint play.

> Oliver commenced by drawing dots and letter-like signs, followed by several ticks (Fig. 4.5). He explained, *"These are ticks. When there are three ticks you can go, when there are two you can't go that way* [pointing]. *I've made two ticks—that means you are not allowed",* then pointing in the opposite direction, *"people allowed in that way*".

Integral to his sign's instructions, Oliver introduced his own idea of differing quantities of ticks to signify rules about entering the car park. In this example, Oliver has begun to abstract meanings, *emulating* Isaac's idea of making a sign but not directly imitating his marks or their meanings.

The communicative nature of the children's self-chosen texts is clear: as they made meanings with signs, they conveyed their ideas to others. The transmission of

Fig. 4.5 Oliver's car-park entry sign

cultural ideas can only disseminated in social contexts, the findings of this recent research suggesting that pretend play can indeed offer opportunities for the *horizontal* transmission of mathematical signs and inscriptions.

4.5 Discussion and Conclusion

In 2008 the government in England published the results of a two-year, government-funded investigation into the teaching of mathematics in early years settings and primary schools (Williams, 2008) asserting,

> The learning processes of very young children require tailored pedagogies and a highly sensitive approach… The review also lays great store by play-based learning of a mathematical nature, and makes specific recommendations regarding early mark-making as a precursor to abstract mathematical symbolism (p. 4).

The chapter on early years mathematics underscored the significance of pretend play and featured Carruthers and Worthington's work on children's mathematical graphics, emphasising, "It is comparatively rare… to find adults supporting children in making mathematical marks as part of developing their abilities to extend and organise their mathematical thinking" (Williams, 2008, p. 34). However, a subsequent change of government resulted in a nationwide shift of emphasis from mathematics to synthetic phonics, thus failing to result in any meaningful changes for the teaching and learning of mathematics in the early years.

The findings of the research featured here confirm that young children already have considerable understandings when they come to nursery school, and that rather than needing adults to directly transmit the signs and symbols of mathematics to them, they possess social learning mechanisms which can complement their existing cultural knowledge, helping them to build on it in social contexts such as rich pretend play.

Seo and Ginsburg (2004) propose that in order to develop an understanding of children's mathematical thinking, adults need to "take the child's perspective, understand the child's current intellectual activities and build on the mathematics to foster the child's learning" (p. 25). Carruthers (2015) acknowledges the importance of children's choices of play and of adults' understanding the mathematical possibilities that their play presents. Adults recognise that mathematical problems children explore belong to them and can be addressed in a variety of ways. They respect and develop children's own thinking, cultivating children's own signs and graphical representations and together with children teachers co-construct mathematical understandings (p. 319). This depends on adults being *insiders* in children's learning through a responsive approach: "as teachers engage in respectful, real conversations, the children become self-aware and are able to articulate their thoughts… [making] it possible to see the children's own mathematical meanings in their play" (Carruthers & Worthington 2011, p. 157), engagement that "privileges children's cultural practices, meaning and purposes" (Wood, 2010, p. 11). The direct teaching of abstract signs and representations is not the only way in which young children learn, and teachers are not the only people from whom they learn. As the examples in this chapter show, play and other open contexts offer complementary and rich possibilities for mathematical learning through *intertextuality*, and social transmission through *imitation and emulation*.

Worthington (2010) contends, "children's thinking and the complexity of their ideas and signs deserve closer attention if we are to understand and truly value their meaning making" (2010, p. 141). van Oers (2010) raised the concern that, "not paying attention to these events (related to children's graphical marking) means that educators may neglect important and stimulating early events for the promotion of mathematical thinking" (p. 32). An integral feature of rich children's pretend play is that it has the potential to open possibilities for natural pedagogy, and for children to develop their understandings of the abstract symbolic language of mathematics. Boyette (2016) emphasises that "play is part of children's practice and how habitus is developed within particular culturally constructed niches [representing] children's autonomous (evolved, not necessarily conscious) preferences for learning cultural roles, values, routines, and meanings through imitative performance" (p. 167).

Neilsen, Cucchiaro and Mohamedally (2012) conclude that play "may serve a critical function in the transmission of human culture by providing a mechanism for arbitrary ideas to spread between children" (p. 1). The status of play "as a cultural transmission device" has earned far less consideration, "yet unless evidence is mustered to suggest child-child interaction has little to do with the spread of cultural ideas, play may yet prove to be equally necessary and worthy of research focus" (p. 4).

In common with many countries, England appears to share in an escalation of prescribed "skills-based" teaching, (Worthington, Carruthers and Hattingh, 2020) often resulting in restricted understandings of children's own mathematics and only limited opportunities for rich play. Unless the culture of early years education changes, opportunities for young children to "bridge the gap" in mathematics that Hughes (1986) highlighted will continue to be confined. Evidence from this recent study suggests that the power of young children's thinking is considerable: in order to cultivate the garden of children's understandings we would do well to heed and nurture it.

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Chapter 5
A Picture Book Pedagogy for Early Childhood Mathematics Education

Liz Dunphy

Abstract The current chapter synthesises a range of international research to argue the case that picture book sharing between children and educator, when appropriately conceived and constructed, can provide a rich and purposeful context in which to promote children's mathematical development and learning. Furthermore, it is argued that the development of a pedagogy for early childhood mathematics education involving the sharing and exploration of picture books should be addressed in a systematic way at preservice teacher education. A comprehensive review of effective early mathematics education revealed that one key factor affecting young children's mathematical development was the kind of purposeful opportunities afforded to them in their early childhood settings (Anthony & Walshaw, 2009). In emphasising that picture book sharing generally involves shared meaning making through language, as well as through interpretation of pictures, this chapter is consistent with the work of early childhood mathematics researchers who have sought to draw attention to the relationships between language and mathematical thinking (see, e.g. Ginsburg, Lee & Boyd, 2008; van Oers, 2013). The chapter begins by addressing key issues implicated in a pedagogy of picture book use in early childhood mathematics education. Three issues are addressed, each of which are examined in relation to their role in promoting learning and teaching: selecting a picture book; supporting children's understanding and communication; and identifying the big mathematical ideas to be developed. In the latter part of the chapter the author discusses her own experience of an initiative designed to help preservice early childhood teachers to develop a pedagogy based on attention to these issues.

5.1 Introduction

A recent report by the Early Childhood STEM Working Group (2017) in the United States points out that while early childhood education and STEM education are both to the forefront in policy and media circles they are rarely talked about together.

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They argue that there is limited high-quality advice to drive effective practice for early childhood STEM education. Their vision for STEM education is based on four guiding principles, two of which are particularly pertinent to the arguments made in this chapter. First, children need adults to foster, guide and build on their interests to ensure adequate early STEM experiences, and to develop their "natural" STEM inclinations. Second, representation and communication are central to STEM learning and this includes discussion, visualisation and other forms of representation including drawing, writing and graphing to promote learning that can lead to generalisation of important concepts and practices. By engaging in such activities even the youngest children at school begin to think in an abstract way. Van Oers (2012) argues that teachers can help the development of abstract thinking through engaging children in schematizing activities characterised by the creation and use of symbolic representations of reality. He uses schematizing activities as a way of improving mathematical thinking. As children use and create drawings to represent their experiences, and discuss and develop them by using invented symbols, their activity becomes more meaningful and more abstract.

Almost a decade ago, Katz (2010) argued that general learning outcomes for STEM education should address children's knowledge and skills as well as their dispositions and feelings related to specific aspects of STEM. In her view effective STEM education in early childhood should focus on the development of disposition and the desire to continue to learn in the areas of science, technology, engineering and mathematics. She challenges pedagogues to be clear about the kinds of intellectually engaging learning experiences that will foster this disposition. She argues for active and interactive experiences that are characterised by intellectual as opposed to academic goals and suggests that "an appropriate curriculum in the early years is one that encourages and motivates children to seek mastery of academic skills … in the service of their intellectual pursuits" (p. 12). In Katz's view, intellectual goals are the ones that focus on sense making and the engagement of children in higher order thinking, such as predicting, hypothesising and justifying and these are often predicated, in early mathematics, on academic skills such as counting and measuring. In what follows, I argue for a systematic approach at preservice level to enable early childhood teachers to develop a picture book pedagogy for supporting early mathematics learning. This pedagogy is one that includes the selection and use of picture books to generate interactive and engaging learning experiences in one aspect of early childhood STEM education, that is, mathematics. It builds on preservice teachers' developing knowledge of the importance of balancing the aesthetic with the pedagogical criteria which research indicates should apply in selecting picture books that appeal to young children. Such knowledge will include, for instance, the importance of assessing the quality of the written text, the quality of the story or plot, the appeal of the illustrations and the interrelationships between text and illustrations. The importance of balancing the aesthetic with the pedagogical is a key value promoted in work with preservice teachers (Nikolajeva, 2016).

5.2 Picture Books as Tools for Learning and Teaching Early Mathematics

The literature argues that teachers of young children should purposefully use a variety of teaching strategies to promote early mathematics learning (Clements, Sarama, & di Biase, 2004). One strategy that is increasingly receiving attention is that of using picture books as tools for the teaching and learning of early mathematics (National Research Council [NRC], 2009). While shared picture book reading has long been a well-researched and promoted practice for the development of aspects of language and literacy in early childhood education (National Early Literacy Panel, 2008), it is now over two decades since it began to emerge in the literature as an important practice for promoting children's early childhood mathematical education (ECME) (Casey, Erkut, Ceder, & Mercer Young, 2008; Young-Loveridge, 2004). However, the challenge of encouraging teachers to develop this aspect of their mathematics pedagogy should not be underestimated since, even in the context of early literacy development, some teachers appear to use picture books infrequently (Dickinson & Tabors, 2001; Pentimonti, Zucker, & Justice, 2011). As reported in Dooley, Dunphy and Shiel (2014), a number of studies have examined the use of picture books (books with pictures and some text, in which pictures have a key role in communicating mathematical ideas) to enhance early mathematical understanding (e.g. van den Heuvel-Panhuizen & Elia, 2012) and to develop young children's disposition towards mathematics (Hong, 1996, Whitin & Whitin, 2004). With these findings come concomitant efforts to articulate a coherent pedagogy of picture book use to support mathematics learning in early childhood education. For instance, Hintz and Smith (2013) offer teachers a three-step planning grid in order to address the issues of selecting, exploring and extending a particular picture book as a resource for learning and teaching. Flevares and Schiff (2014) argue that preservice teachers should be equipped with practices for the effective use of children's literature to support mathematics learning, including the critical evaluation of the quality and integrity of a particular resource, from a mathematical perspective. All of this has implications for early childhood teacher education, and for the development of a pedagogy of picture book use in ECME. In addition, framing efforts to help preservice teachers develop appropriate pedagogies related to the use of picture books must be the idea that development is heavily dependent on the values, ideas, beliefs and experiences of participants. In the study reported here in this chapter, preservice teachers are viewed as active and social learners whose participation and reflection are key elements in their development (see, e.g. Yang, 2015 for a review of theory and research related to sociocultural perspectives on teacher learning).

5.3 Pedagogical Imperatives in Using Picture Books

In what follows, three issues that arise in articulating a picture book pedagogy for early mathematics education are identified. These include: *selecting picture books; identifying key mathematical idea(s);* and *supporting children's understandings and communication*.

5.3.1 Selecting Picture Books

5.3.1.1 A Systematic Approach

The idea of systematic analysis of the content of picture books is relatively new. The framework of *Learning-supportive Characteristics of Picturebooks for Learning Mathematics*, devised by van den Heuvel-Panhuizen and Elia (2012, 34), is an important contribution in respect of evaluating the potential of picture books in ECME. The framework is presented in two parts: *Supply of mathematical content* and *Presentation of mathematical content*. As explained by van den Heuvel-Panhuizen and Elia (2012, p. 19), the framework was designed and tested through collaboration with experts, that is, "those who had carried out studies about the use of picture books in the learning of mathematics as well as authors who have written professional guides about the use of picture books and other children's literature for mathematics education purposes". The authors argue that the framework is especially helpful in recognising characteristics that go beyond discerning typical mathematical content domains. They state that "It helped the experts to discover mathematical processes and dispositions and mathematical themes included in the picture books which were overlooked when they did not use the framework" (p. 42). In assisting the user to keep such elements to the fore in evaluating and selecting a picture book for use in the classroom, the framework is consistent with recommendations that high-quality ECME emphasises an integrated approach to the development of content, processes and dispositions (e.g. Clements, Sarama, & DiBiase, 2004; Dunphy, 2009). However, the assumption implicit in the approach of van den Heuvel-Panhuizen and Elia (2012) is that the expert nominates picture books for mathematics learning and teaching. However, where the teacher is seen as the curriculum expert and the curriculum is developed to be responsive to particular children's interests, strengths and needs, then it follows that the teacher is best placed to select the resource to be used. The question then, as posed by Flevares and Schiff (2014), is not whether the framework is useful but how it may be adopted by teachers for everyday use. A well-grounded framework has the potential to support teachers in appraising those picture books that may intuitively appeal as mathematical teaching and learning resources.

5.3.1.2 Evaluating Specific Features of Picture Books

Many picture books for young children, while not explicitly focused on mathematics, offer rich opportunities for children to be supported in investigating and exploring mathematical ideas. For instance, the classic Eric Carle's (1992:1969) *Hungry Caterpillar* is often presented in the literature as an exemplar of how to engage children in mathematics-related activity (e.g. Hintz & Smith 2013). However, without recourse to an evaluative framework for analysing a picture book, the potential of many popular picture books may be overlooked by teachers, some of whom may remain more focused on children's literacy development rather than on their early mathematics development (e.g. Ginsburg et al., 2008).

In planning for mathematics teaching and learning, teachers may feel safe in relying on *trade books*. These are understood as commercially produced picture books other than textbooks that are oriented towards teaching mathematics, or which aim to provide comprehensive coverage of important mathematical ideas. These books are widely used by parents and teachers and are also to be found in many libraries. They are often targeted at establishing, for example, skills of early numeracy such as counting. These resources are not generally assessed in any structured way in the early childhood mathematical education literature (Hachey, 2015). Powell and Nurnberger-Haag's (2015) analysis of number representations in children's books revealed that some picture books provided children with better opportunities than others to learn about number and counting. Their assessment of the content of a selection of trade books revealed the limited opportunity that these generally provide for children to learn about the number 0 and numbers beyond 10, as well as the limited exposure they offered to multiple representations of number. Such representations are generally considered important for building a strong number sense. Similarly, in their review of children's literature for geometric learning, Flevares and Schiff (2014) cited a study by Hannibal (1999) which showed that not all picture books provide mathematically correct representations of shapes and related geometric concepts. Nurnberger-Haag's (2015) recent content analysis of shape books found that these tended to portray a limited range of shapes in ways that encouraged low-level reasoning, while three-quarters of books had at least one explicit inaccuracy in the way two-dimensional shapes were represented. These findings suggest that trade books cannot always be trusted to present early mathematical ideas in ways that are appropriate and accessible to young children, but they also indicate the extent to which teachers' pedagogical content knowledge is called on when appraising picture books for use in early childhood mathematics education.

Teachers' mathematical talk is critical for children's learning (Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006), and book type influences teachers' mathematical talk during shared book reading. In an effort to increase teacher mathematical talk during shared reading of picture books, Hojnoski, Polignano and Columba (2014) provided specific books (mathematical and non-mathematical) to two teachers. They also provided readers' guides for the teachers' use. The teachers were given individual training in using dialogic reading strategies and prompts, and they were encouraged to incorporate these into the shared picture book sessions. For both teachers the mathematical talk was seen to be greatest when using books with a mathematical focus. This finding suggests that targeting particular resources and skills supports teachers in increasing their impact on children's mathematical learning.

5.3.2 *Identifying Key Mathematical Ideas*

Traditionally, many curricula for young children are focused around the five strands of number, shape and space, measure, data and algebra (e.g. Bowman, Donovan & Burns, 2001; Dunphy, 2009; NRC, 2009). Within and across each of these strands there are key ideas or concepts/conceptual domains that are referred to as *big ideas*; they are referred to as *big* because they are "deeply connected to the structures of mathematics … [and] also characteristic of shifts in learners' reasoning" (Fosnot & Dolk, 2001, p. 11). Clements and Sarama (2009, p. 3) define the big ideas of mathematics as "clusters of concepts and skills that are mathematically central and coherent, consistent with children's thinking, and generative of future learning". They are important for teachers to bear in mind because addressing these in a systematic way in early childhood education optimises the possibilities that children develop the essential organising structures that help them relate mathematical ideas (e.g. Fuson, Kalchman & Bransford, 2005).

Brownell, Chen and Ginet (2014) identify 26 big/key ideas for children aged 3–6 years and they cluster these around each of the themes of: sets; number sense; counting; number operations; pattern; measurement; data analysis; spatial relationships; and shape. For example, in relation to measurement, the key ideas are:

- Many different attributes can be measured, even when measuring a single object;
- All measurements involve a "fair" comparison;
- Quantifying a measurement helps us to describe and compare more precisely (99).

The authors argue that teachers can use such ideas to guide their activity planning, classroom conversations and responses to children's queries.

5.3.3 *Supporting Children's Understandings and Communication*

5.3.3.1 Supporting Mathematisation

Talking in the context of picture book sharing has the potential to promote children's ability to *mathematise*, that is, to interpret and express the events in the story in mathematical form and to understand the relations between the two (e.g. Ginsburg, 2009). Drawing on Sfard's (2008) definition of mathematising as participation in mathematical discourse, Gejard and Melander's (2018) study of preschool children's participation in geometric discourse shows the symbiotic relationship that exists between talk, gesture and the material environment, where talk and gesture mutually elaborate upon each other as part of collaborative meaning-making practices. Clements et al. (2004) argue that children need opportunities to bring their extensive experiential knowledge to an explicit level through mathematisation. This involves processes such as reasoning, representing, problem-solving, connecting and communicating. The rich environment of the picture book and the ensuing discussion and interactions with the teacher and peers all provide scope for children's engagement in mathematisation. As they participate in the discussion of the story and pictures, children's involvement can include the use of narrative incorporating mathematical words, ideas and symbols as well as reference to visual objects or symbolic artefacts. The type of language used in mathematising needs to be supported and developed (e.g. Ginsburg, 2009; Perry & Dockett, 2008) and the sharing of the picture book provides a context in which the teacher can provide that support. As reported in Dunphy (2015), optimum support is provided when the teacher understands that ways of learning, doing and communicating mathematics are heavily dependent on conversation. Children may express mathematical reasoning, represent mathematical knowledge, explain mathematical thinking and understanding, and communicate their mathematics in a range of ways, not just through language. For instance, they may use particular tools such as drawings (e.g. van Oers, 2013).

5.3.3.2 Developing Math Talk

From a pedagogical perspective, it is essential that young children are supported to engage in math talk, that is, talk which indicates their participation in mathematical thinking processes as well as talk that involves their use of the specialised language (vocabulary) of mathematics. But as van Oers (2013) observes, young children's use of mathematical words is not by itself a sign of mathematical thinking, "Mathematical thinking essentially requires *reflection* on (the relationships among) mathematical objects i.e. relate different mathematical objects (like numbers), explain operations with number, evaluate the use of mathematical notations, in short: it calls for the ability to communicate with oneself or other people *about* mathematical objects and their interrelationships" (p. 191). A pedagogy which promotes children's development and learning through reflection not only requires teachers to support and promote children's mathematical thinking but also requires the ability to engage children in extended communication about the mathematics in hand in order to relate teaching strategies to children's developing conceptual understanding. Arguably, situations where teachers are handed the picture books, and given guides as to how to engage with children can be seen as militating against the responsive, co-constructive pedagogy, which is central to current thinking on how best to support early learning (e.g. Jordan, 2004). Interactions characterised by sustained shared talk and thinking are best predicated on active engagement with, and extension of, the child's ideas (e.g. Sylva, Melhuish, Sammons, Siraj-Blatchford, & Taggart, 2004). This pedagogy is one which results in rich and challenging conversations characterised by elaborative follow-up of the child's interpretation and ideas (e.g. Mascareño, Deunk, Snow, & Bosker, 2017).

Elia, van den Heuvel-Panhuizen and Georgiou (2010) argue that an important task for the teacher is to examine all of a book's pictures carefully, and then to consider their function in relation to the accompanying text before deciding on the kinds of teacher interactions that might best serve to optimise children's mathematical thinking. In their study van den Heuvel-Panhuizen and Elia (2013) introduced certain specifications to teacher participants on how best to approach the reading of mathematically related picture books. The teachers were asked to let the books do the work and "not to ask too many questions … to maintain a reserved attitude and not to take each aspect of the story as a starting point for an extended classroom discussion" (p. 239). Teachers were encouraged to engage in some discussion with the children and to engage them cognitively, but to use interactional strategies such as asking oneself a question; playing dumb, or just showing an enquiring expression. All of the strategies recommended were found to be effective in getting children actively involved in the mathematics-related events in picture books. According to the authors, they elicited mathematical activity, thinking and problem-solving. Picture books used in such focused ways are likely to have a positive effect on the teachers' use of math-related talk, which is itself significantly related to the growth of young children's mathematical knowledge over the school year (Klibanoff et al., 2006).

5.4 A Framework for Preservice Teachers

The framework of *Learning-supportive Characteristics of Picturebooks for Learning Mathematics*, developed by van den Heuvel-Panhuizen and Elia (2012), was the main inspiration and impetus for the work described in this chapter. This framework was used with inservice Master's level early childhood teachers specialising in ECME with moderate success, but was judged to be too complex a tool with which to introduce picture book use to undergraduate preservice teachers taking an ECME course in Year 2 of a four-year programme. Consequently, a new simplified framework to guide preservice teachers in selecting and using picture books for early mathematical learning was devised (see Table 5.1). The new framework responds to the issues raised in the discussions in earlier sections of the chapter here regarding articulating a picture book pedagogy for ECME, while at the same time recognising the centrality of the elements inherent in van den Heuvel-Panhuizen and Elis's framework. The *Framework for Selecting and Using Picture Books for Early Mathematics Education* (framework SUP) supports preservice teachers to select picture books and analyse their characteristics in ways consistent with their developing knowledge about early mathematics learning. It takes into account the relative inexperience of preservice teachers as well as their potential for developing their ideas about high-quality ECME. Framework SUP orients them to attend to aspects of pedagogy as highlighted in the discussions about pedagogical imperatives above. It promotes a systematic approach

Table 5.1 Framework for selecting and using picture books in early childhood mathematics education (Framework SUP)

Presentation	Content	Children's participation
1. How is the content presented? Explicit/implicit (i.e. not directly explained) 2. Is there mathematical content visible but not related to the story itself? 3. Will the content engage the children in a mathematically meaningful way? 4. How does the story/picture book relate mathematics to children's lives, interests and experiences? 5. How might the mathematical content be integrated with other areas of learning, e.g., through social pretend play? 6. How might the story/picture book make understanding possible at different levels; offer multiple layers of meaning; anticipate future concept development?	1. What mathematical processes does the book support? e.g.: • using mathematical language • reflecting on mathematical activities • solving mathematical problems • mathematical reasoning 2. What key ideas are encountered? • Sets • Number sense • Counting • Number operations • Pattern • Measurement • Data Analysis • Spatial Relationships • Shape 3. What strand of mathematics can be developed? e.g.: • number • algebra • shape and space • measure • data 4. What aspect of the content is addressed?	1. What activities will arise from the story/picture book? 2. What communication modes might children use to engage mathematically with the activities? 3. How might children demonstrate receptive understanding of the mathematics? 4. What mathematical language will be developed as a result of engagement with the story? 5. What questions will be key to provoking children's participation and discussion? 6. What kinds of discussion might arise, and how will the children be supported to mathematize? 7. How will children's engagement in mathematical discussion be maximised?

Derived from: van den Heuvel-Panhuizen, M., & Elia, H. (2012). Developing a framework for the evaluation of picture books that support kindergartners' learning of mathematics. *Research in Mathematics Education*, *14*(1), 17–47

to using picture books in early childhood mathematics by foregrounding particular issues. Teachers are guided to select books based on consideration of these. They can justify their choices on clear ideological grounds, and they can articulate key mathematical ideas that may be explored with children using the book selected. They can consider opportunities to support children in mathematising the events that occur in the story and the objects and images that feature in the pictures. They can plan to engage children in the kind of mathematical talk that will promote each child's ability to engage in mathematical thinking processes. In addition teachers can identify specific play-based learning opportunities to extend and deepen children's engagement and understanding of mathematics in intentional ways. These can provide teachers with opportunities to incorporate varying levels of involvement in play to support the children's learning by working along a continuum of understanding of classroom play, judging when to engage in directing, collaborating with or extending the child's lead during times of play in the classroom (see, e.g. Pyle & Danniels, 2017).

Each part of the framework has a number of elements to guide teachers' analyses of picture books for mathematical purposes. The elements were informed by the key emphases participants were familiarised with from their coursework: the selection of picture books; the recognition of key mathematical idea(s) in picture book contexts; and issues related to supporting children's understandings and communication. The idea of implicit and explicit content presentation is one that is foregrounded in the framework, since recognising possibilities for mathematical learning is especially important in early childhood education where an integrated and play-based approach is important. Framework SUP also draws attention to ways in which children's participation in mathematics learning can be supported, with particular attention to engaging children in discussion, co-constructive meaning making and processes such as explaining and reasoning.

5.5 Trialling the Framework

5.5.1 Purpose

A trial was carried out to see how preservice teachers used the framework. I wanted to see which elements of Framework SUP were influential in participants' choices of picture book, and indeed if other issues beyond the framework emerged as important. Preservice teachers who attended the authors sessions for the relevant module on Mathematics in the Early Years at School in the previous academic year (2015) were invited to participate in the trial reported here. Important themes in the module included the development of key ideas, the promotion of children's participation in mathematical processes and the promotion of their abilities to mathematise. Course content included input on the role of picture books in teaching and learning early mathematics. The module assignment required preservice teachers to select a picture book and to plan related learning experiences to offer children (4–6 years) during school placement. In preparation for the module assignment students were asked to use Framework SUP to complete an in-class small group task focused on using Framework SUP to examine the potential of a story book. There were a number of aspects to the assignment. The preservice teachers first engaged with some readings and then synthesised the case for the use of picture books for mathematics learning and teaching with young children. They then selected a picture book and wrote a short rationale for their choice (50 words). The final element of the assignment required them to describe five possible learning experiences to assist in the learning and teaching of some (specified) key idea(s). The preservice teachers were asked to consider throughout opportunities in which they would engage children in mathematical discussion. Grades for the assignment were awarded at the end of the academic year 2015–2016.

Ethical approval for this project was obtained from the Research Ethics Committee of the University in which the author worked at the time. Ethical issues were addressed throughout in line with the EECERA Ethical Code (Bertram, Formosinho, Gray, Pascal, & Whalley, 2015). While other options were available, it was felt that given the power issues involved and the vulnerability of the student population, an online request was the best way to convey the "no pressure" dimension of participation to students who, while no longer in a power relationship with the lecturer involved (the course was finished), were nevertheless still students of the university. Every effort was made to reach the target population. An initial personalised email was sent to all prospective participants in early January 2017 when students were on an inter-semester break. A follow-up personalised reminder email was sent in the week before students returned to college. A total of 20 students from a possible 69 responded to an email request, of these 16 agreed to participate, two no longer had the material requested and two declined to participate. Given that the population targeted had attended weekly classes for one semester with the lecturer seeking the data, the response rate was disappointing. However, Lefever, Dal and Matthíasdóttir (2007) point to issues with low response rates when participants are contacted online, with rates of between 15 and 29% in online surveys commonly reported. Given the 23% response rate achieved, it must be recognised that there may be some bias in the data since it was possibly the most diligent and interested students that responded, and consequently, these may have been students who had given most attention to their assignment in the first place.

5.5.2 Method and Analysis

This paper analyses and reports data pertaining to participants' written rationales for choosing particular books in order to ascertain the extent that issues foregrounded in the framework were referenced. A documentary analysis (Bowen, 2009) of the data was carried out on the participants' assignments. This involved engagement in the processes of skimming, reading to examine the documents more thoroughly and interpretation. A content analysis was then carried out on participants' rationales for their choice of picture book (e.g. Denscombe, 2007). Each rationale was a unit of analysis. As a first step in the analysis, the rationale was extrapolated from each assignment. Each unit was numbered and coded. The categories used to carry out the analysis were drawn from the elements of Framework SUP, with other categories added as they arose in the data. Every effort was made to be objective but sensitive in analyzing the narratives offered. In order to ensure that participants' thinking and decision making in choosing a particular book was captured, subcategories (drawn from the elements of each of the three areas of Framework SUP) were introduced and the main and subcategories were entered onto the text. When all the units were coded a count was carried out to ascertain the frequency with which categories/subcategories arose in participants' accounts.

5.6 Findings

The findings reported here indicate the factors which appeared to influence participants' choices of picture book. Of the 16 submissions, 15 were analysed. One was excluded because the participant did not include in her submission the rationale for her choice of picture book.

5.6.1 What Influences Guided Participants' Choices of Picture Books?

5.6.1.1 Presentation

Almost all participants (13) referred to elements of the *Presentation* aspect of Framework SUP as influencing their choice of picture book. Seven referred to the explicit/explicit nature of the content as being important. For example,

> I chose the book *Washing line* ....The mathematical content is implicitly presented leading to interesting and engaging activities in which the children can easily relate to especially with their washing lines and at home and clothing. (P2)
>
> I chose this book [*The bad tempered ladybird*] ...The mathematical content is presented visually in the illustrations and orally in the literature i.e. it is explicit. (P10)
>
> The content [*Five little ducks*] will engage the children easily in maths as it uses appropriate pictures. (P12)

Four participants referred to the potential of the picture book to engage children in a mathematically meaningful way. For example, "I selected this book [*Lemonade in winter*] because I thought it had plenty of opportunities for mathematical learning around the topic of money" (P7).

Five participants focused on the ability of the picture book to relate mathematics to aspects of children's lives, interests or experiences. For example,

> This book [*I am absolutely too small for school*] has the characters Charlie and Lola in it, which the children will be familiar with from the TV show. I would use this book with Junior Infants [i.e. 4/5 year old children] as they can relate to the nervous feelings of starting school for the first time. (P14)

With reference to the picture book *The very hungry caterpillar* "the range of references to number as well as the use of mathematical language throughout ... makes maths relevant to the lives of children and allows them to see how maths is integrated in the real world" (P9).

5.6.1.2 (Mathematical) Content

Thirteen participants focused on the *Content* aspect of Framework SUP. Three reported that they were influenced by what they saw as the potential of the picture book for focusing on the development of mathematical processes. For example,

> Children will be using mathematical language by counting the fruit that he ate and using number talk such as how many pieces he has eaten altogether. Children have opportunities to discuss and justify conclusions of activities. (P5 in relation to *The very hungry caterpillar*)
>
> Essential mathematical language will be developed from the use of this book, including words such *as tallest, smallest, most, least, how many, empty, full.* (P6, in relation to *How many seeds in a pumpkin?*)

Twelve of the participants made reference to the potential that their chosen picture book offered to promote children's understandings related to one or more of key idea(s) in early mathematics. For example "The counting skills are obvious in this book as well as some underlying mathematical concepts such as patterns and measurement (P3 in relation to *The very hungry caterpillar*)."

> One of the reasons I chose this book was because the book is about a group of kids working together to make sure all the kids present get an equal amount of Ma's cookies! This immediately showed me that this book would be ideal for introducing the mathematical concept of division. (P8 in relation to *The doorbell rang*)
>
> I chose this book because it can be used in the classroom to focus on the big idea of measurement, addressing the concepts of time. (P10 in relation to *The bad tempered ladybird*)."

5.6.1.3 Participation

From the rationales offered by participants on the *Participation* aspect of Framework SUP, seven participants indicated how their choice of picture book had potential to promote children's participation in mathematics. Two made references to activities that would arise from their picture book and so promote children's participation. "There are many activities that will arise from the story (children's participation)" (P12). P16 stated that "When I first read the book, ideas for maths activities came to mind immediately."

Three participants focused on the potential that the picture book offered for the development of children's mathematical language, though none mentioned how children would be supported to use that language.

Two participants chose to foreground the discussion element of children's participation. For example, P5 talked about children having "opportunities to discuss and justify conclusion of activities." The same participant linked this to formative assessment of children's mathematics, that is, "observation of children's thinking during activities provides a vital mode of assessment." P10's statement was more specific as to what the children might discuss "The children will use mathematical language and reasoning related to time, for example, the ladybird woke up at this time because he wanted his breakfast."

5.6.1.4 Author Recognition

Two other influences were mentioned by a small number of candidates. Both P4 and P16 stated that they chose their picture books based on the identity of the authors, indicating a pragmatic approach to the work they were asked to do. "I chose this book because our lecturer had told us that Pat Hutchins books usually involve explicit mathematical content" (P4).

> I went with this author because I knew that there would be opportunities for mathematical teaching based on other books I have read by Carle…I also thought that gathering resources to accompany the story [*Ten little rubber ducks*] and activities would be simple. (P16)

5.6.1.5 Personal Response

Their personal response to a particular picture book was cited by two participants as important for them in choosing a picture book for use in their planning for early childhood mathematics education. "I chose this book [The very hungry caterpillar] because I remember it from school and I loved it (P3)." The other commented "I was drawn to its colourful and clear illustrations" (P8).

5.7 Discussion

In this small trial, the *Framework for Selecting and Using Picture Books for Early Mathematics Education* (Framework SUP) was seen to be effective in supporting preservice teachers to critically analyse picture books and to plan towards optimising learning experiences in keeping with current emphases in early childhood mathematics education. While no generalisation can be made on the basis of the findings here, they would suggest that participants were consistently considering the three categories and particular subcategories highlighted in Framework SUP as they set about appraising picture books for mathematical purposes. A small minority of participants explicitly identified additional factors, that is, *author recognition* and *personal response* as important factors in influencing their selection of a picture book. It is possible that these factors, while not explicitly identified by other participants, also played an important part in guiding some participants' initial orientation to a particular picture book. In other words, as discussed in the literature review above, sociocultural issues interacted with professional issues as participants selected and analysed a particular picture book. In retrospect, the 50-word guide constrained participants' responses to the question of factors of influence in the selection and analysis of the picture book. It forced them to foreground their reporting of some factors over others. A more detailed narrative from the preservice teachers as to how the elements of Framework SUP influenced their thinking in book selection would have afforded participants better opportunities to give a more comprehensive account of their thinking in their justification of their chosen resource. For example, while only seven participants referenced the *participation* element of the Framework SUP, a reading of the planned learning activities part of the submissions clearly shows comprehensive attention to participation by children. The documentary analysis clearly showed that as students worked to complete their assignments, they moved systematically through the elements highlighted in the Framework SUP. But it also showed a discernible flexibility about the way the participants used the elements of the framework and brought them together in ensuring that all were covered in their assignment. The fact that there were other aspects to the assignment besides the rationale aspect allowed the participants scope to show the flexibility and comprehensiveness of their thinking.

There is a strong argument that a framework encompassing key issues of early childhood mathematics pedagogy can support the development of a picture book pedagogy for ECME. Given its potential, teachers must acquire skills to use this pedagogy in an intentional and systematic way. Their efforts should be characterised by engagement of children in rich, challenging and co-constructive conversations, and with due attention to the key ideas of early childhood mathematics. All of this is in keeping with the advice outlined at the beginning of this chapter from The Early Childhood STEM Working Group (2017) that effective practice must be based on strong adult guidance and on supporting young children's abilities to communicate, represent and generalise. This is not to promote a one-size fits all pedagogy for this key element of STEM education. From a professional perspective, teachers must first and foremost be responsive to the children they teach, and they must also be free to pursue particular curriculum/mathematical imperatives as they see fit. The way in which teachers chose to integrate a picture book pedagogy with the range of other pedagogies they use to promote early mathematical learning for their particular group of children is an issue that is at the heart of professional practice and consequently best decided by individual teachers. Teachers may sometimes explicitly plan mathematical discussion and other activities, such as schematizing based on a particular picture book, while at other times they may engage in unplanned mathematical activity in response to children's interest in a particular book (e.g. Wager, 2013). In either scenario, general principles about factors arising in selecting picture books must apply. The strategy of using picture books is envisaged as being interrelated with other strategies in use in the classroom. For instance, the picture book can be seen as a frame for curriculum planning and a context within which to develop play-based learning. Participants were orientated in course work towards an integration of perspectives and practices on classroom play, with different types of play perceived as complementary rather than incompatible, and with a view of play as serving a variety of developmental and academic learning domains (for example, Pyle, De Luca, & Danniels, 2017). Although not the focus of the trial reported here, participants provided a range of play-based learning opportunities for children as part of their schemes of work for mathematics. For instance, several participants choose *Washing Line* (Alborough, 1993) as the focus picture book and planned play-based learning opportunities accordingly and with a range of resources. One participant using this picture book noted her planning/provision along the play continuum as including free play in the play corner/laundry and with opportunities for structured play to support specific mathematical learning explicitly identified also: Ordering, estimating measuring, checking by trying on for size, creating patterns, exploring patterns, copying patterns, extending patterns. She also identified a range of opportunities for integrating learning across other aspects of the curriculum including music.

5.8 Implications

It is important to emphasise that the *Framework for Selecting and Using Picture Books for Early Mathematics Education* (Framework SUP) presented and discussed in this chapter is not seen as a substitute for the framework of *Learning-supportive Characteristics of Picturebooks for Learning Mathematics* devised by van den Heuvel-Panhuizen and Elia (2012). Rather, Framework SUP is a response to a perceived need to help early childhood preservice teachers to begin to work in a systematic and rigorous way in selecting high-quality picture books as learning and teaching resources in ECME. The frameworks speak to different audiences; Framework SUP can be viewed as a resource to be used by teacher educators with preservice teachers, whereas the van den Heuvel-Panhuizen and Elia framework might be conceived as a professional development tool for early childhood teacher educators to inform themselves of the range of issues inherent in the promotion of picture books in ECME, and a point from which to develop their own work with preservice teachers. The Framework SUP is not seen as definitive but can be used as a resource, a starting point from which individual early childhood mathematics teacher educators can work in order to develop and further refine it for their own use. It is envisaged that any such development and refinement might reflect particular ECME contexts, teacher education course work emphases, as well as individual interpretations of, and reflections on the seminal work of van den Heuvel-Panhuizen and Elia.

In conclusion, this trial indicates important lines for development in the education of teachers of early childhood mathematics. In particular, it indicates the need for tools such as Framework SUP which synthesise the issues and guide pedagogy in the area of selecting and using picture books in ECME, and which are usable by teachers in their everyday work with children.

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Chapter 6
Making STEM Visible in Early Childhood Curriculum Frameworks

Amy MacDonald and Carmen Huser

Abstract Increasingly, education systems around the world are implementing national curriculum frameworks for early childhood education settings. However, the disciplines of science, technology, engineering, and mathematics are not always explicitly articulated in such frameworks, and consequently, the potential for STEM learning within these frameworks is not always well understood. In this chapter, we offer a counter argument to the "typical" justification of STEM education that it is in nations' interest to develop a STEM literate workforce in order to be economically competitive on a global level. Instead, we highlight a child-rights perspective for STEM education in the early years, elucidating the potential access to STEM education afforded through national early childhood curriculum frameworks. This chapter interrogates the national early childhood curriculum frameworks of Australia, New Zealand, and Sweden in order to demonstrate how STEM can be made visible in such frameworks.

6.1 Introduction

In recent years, the disciplines of science, technology, engineering, and mathematics (STEM) and their integration into early childhood education (ECE) have received increased attention. This interest intersects with decreasing student numbers in later STEM professions (Aldemir & Kermani, 2017), as well as the development, implementation, and revision of national curricula for the early years in education systems around the world. At least for the last decade, many governments have pushed the STEM agenda into the early years to ensure children develop interest in STEM and are equipped for the digitised workforce, with professions increasingly in need of

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STEM skills (Clark-Chiarelli, Gropen, Fuccillo, & Hoisington, 2013; Cohrssen & Page, 2016; McClure et al., 2017).

In this chapter we offer a counter argument to the "typical" justification of STEM education that it is in nations' interest to develop a STEM literate workforce in order to be economically competitive on a global level (DeJarnette, 2018; Park, Dimitrov, Patterson, & Park, 2017). Rather, this chapter highlights a child-rights perspective for STEM education in the early years. This is in light of contemporary global actions for sustainable development goals (SDG) which "can be seen as an operational plan for realising human rights" (Danish Institute for Human Rights, 2018, p. 8). Globally, all nations face challenges towards sustainable development, and STEM education plays a major role in reaching the UNECSO agreement on SDG where a STEM literate citizenry has been identified as a key driver (Fensham, 2008). Children have rights to life, education, and to express their views in matters that affect their lives (United Nations, 1989). In consideration of children's lives in the twenty-first century, their rights should lead the STEM agenda, ensuring that all children have access and equitable opportunities to STEM learning.

Education systems around the world are implementing national curriculum frameworks for early childhood education settings to ensure equitable access to high-quality early education. However, the disciplines of science, technology, engineering, and mathematics are not always explicitly articulated in such frameworks, and consequently, the potential for STEM learning within these frameworks is not always well understood. This chapter examines three international examples of national curriculum frameworks for early childhood education, namely: 1. *Belonging, Being and Becoming: The Early Years Learning Framework for Australia* (Australia; Department of Education, Employment, and Workplace Relations [DEEWR], 2009); 2. *Te Whāriki* (New Zealand; Ministry of Education, 2017); and 3. *Läroplan för Förskolan* (Sweden; Skolverket, 2010).[1] These three curriculum frameworks were selected because they were familiar to the authors through their previous research and professional experience. Moreover, the use of three examples provides a rich opportunity to identify the visions, beliefs, and ideas that underpin these different approaches to early childhood curricula (Soler & Miller, 2003). The aim is not to compare these countries, nor is it to make judgements about the "quality" of the frameworks. Rather, the intent is to synthesise the different approaches taken in these three curriculum documents (Rasinen, 2003) in order to illustrate the potential for STEM education in early childhood curricula.

6.2 Background

The integration of science, technology, engineering, and mathematics (STEM) into early childhood education (ECE) has received much attention in the last decade which is reflected in the growing number of publications. A systematic literature

[1] Skolverket is the Swedish National Agency for Education.

search using the database EBSCOhost (Education) which includes *Academic Search Complete, Education Research Complete, ERIC, Psychology and Behavioral Sciences Collection* and *SocINDEX* for full-text search revealed, until 2008, one or two publications per year that dealt with STEM in ECE. From 2009, with eight publications, numbers increased each year and four folded in 2018. A strong driver for STEM support in ECE derives from recent societal issues, such as the increase of new technologies in everyday life.

For at least the last decade, many governments around the world have been in pursuit of a STEM skilled workforce and a STEM literate citizenry (Gough, 2015; Park et al., 2017), and STEM education has been positioned as the key strategy for achieving these goals (Murphy, MacDonald, Danaia, & Wang, 2018). Whilst nations strive for an economically competitive and strong STEM literate workforce, there is concern of decreasing student numbers in later STEM professions (Aldemir & Kermani, 2017). However, the notion of compatible economies is one argument. Equipping children with skills for the digital age is also seen as a necessity, since it is estimated that professions requiring STEM, including digital literacy will dominate the workforce (Clark-Chiarelli et al., 2013; Cohrssen & Page, 2016; McClure et al., 2017). Thus, furthering STEM skills in the younger generation is for their benefit to suit and give them equitable access and opportunities in the job market.

Today, the responsibilities of those countries in collaborative partnership with UNECSO, including Australia, add another argument that socially and environmentally sustainable development needs a supply of scientifically and technologically skilled professionals to drive it, and the preparation of a scientifically and technologically informed citizenry to guide it (Fensham, 2008). Conversely, the Incheon Declaration for Education 2030 recommended the strengthening of STEM education as a key strategy for meeting its 17 sustainable development goals (SDG) and 169 targets (UNESCO, 2015). This argument, while still having some focus on the STEM educated workforce, provokes us to think further. STEM literate citizenry is essential for nations globally and for all human beings' lives and their wellbeing within not only economic but social and environmental dimensions of sustainable development (UN General Assembly, 2015, para. 3). This argument leads into recognizing a human-rights approach to STEM education. The SDG and their targets are strongly interconnected with human rights and international treaties that outline such rights. In fact, the SDG "seek to realize the human rights of all" (UN General Assembly, 2015, para. 3).

In relevance to this chapter, SDG 4, for example, envisages quality education, promoting inclusive, equitably accessible education with the aspiration for lifelong learning. Education, in this sense, is also a human right, as stated in the *Universal Declaration of Human Rights* (UN General Assembly, 1948, Art. 26), and in the *Convention on the Rights of the Child* (CRC) (United Nations, 1989, Art. 28).[2]

[2]These linkages between the SDG, targets and core international human right instruments can be searched and visualised with the *Human Rights Guide to the Sustainable Development Goals* (Danish Institute for Human Rights, 2018) which is accessible online (see http://sdg.humanrights.dk/en).

Under SDG 4, target 4.4 states: "[b]y 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship" (UNESCO, 2015, p. 42). Target 4.7 promotes that "all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, […] global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development" (UNESCO, 2015, p. 48). These build on the accomplishment of target 4.1 and 4.2 to ensure that all children have access to quality pre-primary, primary and secondary education.

Concretely, these targets can be underpinned with the CRC's Article 29 that exemplifies Article 28, the right of the child to education, such as that education should be child-friendly, and aim to promote children's developing respect for the natural environment (United Nations, 1989). Further explanation of Article 29 complements the rights-perspective for STEM learning where education as a right of the child "is one designed to provide the child with life skills" (UN Committee on the Rights of the Child, 2001, para. 2). Considering the sustainable development dimensions and children's life contexts in the twenty-first century, STEM skills are and will continue to be critical for their development and lives now and in the future. A look at the CRC's third section of Article 28 underscores that this right demands nations to provide education that fosters STEM literacy through "facilitating access to scientific and technical knowledge" (United Nations, 1989, Art. 28.3). In a similar arguing manner, Cohrssen and Page (2016) apply a child-rights approach to mathematics education and identify an "ethical obligation" (p. 104) for fostering mathematical concepts in children in response to demands of the digitised societal contexts in which they grow up and live.

From a child-rights perspective, the duty to ensure children develop life-essential skills receives attention and needs expansion for STEM learning in light of the SDG. For example, SDG 13—Climate Action aims to "improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaption, impact reduction and early warning" (target 13.3, UN General Assembly, 2015, p. 23). In reaching this target, a range of STEM capabilities, which have been identified from reviewing the literature on effective STEM education and from analysing STEM education strategy documents in Australia (Murphy et al., 2018), come into focus, such as critical thinking, investigating, analysing, and creative and complex problem-solving, among others. Nations need critical thinkers to tackle the challenges they are facing for sustainable development. At least a decade before the 2030 Agenda for SDG (UN General Assembly, 2015), children have been considered as active citizens who are to contribute to global topics, such as the environment, to increase capacities in problem-solving (Jans, 2004). In turn, children as rights holders should be able to express their views and be heard in matters concerning their lives (United Nations, 1989, Art. 12) which requires that they have the capabilities to share their opinions and STEM knowledge to contribute to decision-making in matters related to sustainable living.

A growing body of child development research advocates for early STEM learning. Mathematical skills have been found to develop at an early age, including number sense and ordinality, which are strong predictors of later academic success (Hunting, Mousley, & Perry, 2012). Additionally, young children's self-belief in their ability to learn, for example, science is enhanced through early, meaningful experiences of science and show greater interest in science (Patrick, Mantzicopoulos, & Samarapungavan, 2009, pp. 182–3). Such experiences have also high potential to trigger an appreciation for science and its value to everyday life (Fleer, March, & Gunstone, 2006). For children from disadvantaged families, ECE settings might be their only environment where they will have access to such experiences, adding an equity and social justice point of view (Cohrssen & Page, 2016). Having in mind that the early childhood years lay the foundation for future learning in STEM (Campbell, Speldewinde, Howitt, & MacDonald, 2018), the rights of even the youngest child to education and to participation add an important dimension to the responsibility to ensure early STEM education opportunities.

6.3 Overview of Curriculum Frameworks

In early childhood education, "curriculum" is a complex concept containing multiple components, such as goals, content, and pedagogical practices (Litjens & Taguma, 2010). Early childhood curriculum frameworks typically stand in contrast to "school-type curriculum (based on the acquisition of pre-defined skills and knowledge items)" (OECD, 2004, p. 16). Rather than having distinct and explicit disciplines such as STEM areas outlined, early childhood curricula tend to take a holistic approach to children's learning and development, considering every experience, activity, or event within the ECE setting as learning that is set in their sociocultural environment. ECE curricula are "influenced by many factors, including society's values, content standards, research findings, community expectations, culture and language" (Taguma, Litjens, & Makowiecki, 2013, p. 12). In the following sections, we outline a brief overview of the history, development, and key characteristics of the three curriculum frameworks analysed in our study.

6.3.1 Belonging, Being and Becoming: The Early Years Learning Framework for Australia

Belonging, Being and Becoming: The Early Years Learning Framework for Australia (EYLF) is Australia's first national curriculum framework for ECE. The EYLF was developed in 2009 by the Council of Australian Governments "to assist educators to provide young children with opportunities to maximise their potential and develop a foundation for future success in learning" (DEEWR, 2009, p. 5). The introduction of the EYLF was a key element of a wider reform agenda that "positioned ECE as both an educational good—preparing children for school and helping ameliorate educational disadvantage—and, within a neoliberal paradigm, as a means for enhancing future workforce participation and productivity" (Hard, Lee, & Dockett, 2018, p. 5). The framework is underpinned by the UN Convention on the Rights of the Child, and commits to supporting Goal 2 of the Melbourne Declaration on Education Goals for Young Australians, that "All young Australians become successful learners; confident and creative individuals; and active and informed citizens" (Ministerial Council on Education, Employment, Training and Youth Affairs, 2008).

The EYLF is not intended to be prescriptive in its content or pedagogy; rather, "it provides broad direction for early childhood educators in early childhood settings to facilitate children's learning" and "guides educators in their curriculum decision-making" (DEEWR, 2009, p. 8). It is structured around five outcomes for children's learning, namely:

1. Children have a strong sense of identity;
2. Children are connected with and contribute to their world;
3. Children have a strong sense of wellbeing;
4. Children are confident and involved learners; and
5. Children are effective communicators.

The potential for STEM is not immediately obvious in the five outcomes; however, as MacDonald (2018) notes, with careful reading, it is possible to elucidate the STEM opportunities embedded in these outcomes—in particular, Outcome 4 which emphasises dispositions such as curiosity and persistence, skills such as problem-solving and hypothesising, and the transfer of knowledge from one context to another (DEEWR, 2009). This study builds on MacDonald's initial exploration to offer a more comprehensive interrogation of the possibilities for STEM embedded in the EYLF.

6.3.2 Te Whāriki

Te Whāriki is the first national curriculum framework for all early childhood education and care services in New Zealand, developed and first published in 1996. A bicultural frame that places all children's growth and learning at the heart builds on Māori conceptual understandings, embracing New Zealand's diverse society and its early childhood educational landscape. It acknowledges Te Tiriti/The Treaty of Waitangi, which was signed by Māori chiefs and British Crown representatives during colonisation, with the purpose to promote the partnership between Māori and Pākehā citizens within the educational context. As a result of paying respect to their language and culture, it aims to ensure that Māori children succeed in their educational journeys from the early years, with extending this to the education of all children living in New Zealand. It was purposely developed in consultation with early learning organisations and services and in collaboration with the Kohango Rea National Trust for Māori immersion early childhood programmes. Since its first publication, Te Whāriki has just recently been revised and updated in consideration of children's contemporary lives in the twenty-first century. However, its vision of children as "competent and confident learners and communicators, healthy in mind, body and spirit, secure in their sense of belonging and in the knowledge that they make a valued contribution to society" (Ministry of Education, 2017, p. 6) continues to set the scene for the framework.

Te Whāriki is symbolised through a woven mat that has a basic weaving pattern; four principles and five strands (Ministry of Education, 2017). The principles encompass empowerment/whakamana; holistic development/kotahitanga; family and community/whanau tangata; and relationships, and address pedagogical and practical curriculum decisions. The strands are areas of learning and child development, including wellbeing/mana atua; belonging/mana whenua; contribution/mana tangata; communication/mana reo; and exploration/mana aotūroa. Te Whāriki can also be translated with a "mat for all to stand on" (Ministry of Education, 2017, p. 10). In this sense, it is a framework that gives orientation through these set principles and strands which are weaved together, and each ECE setting starts their own weaving of the curriculum mat. While providing a frame and structure for pedagogical curriculum planning, Te Whāriki acknowledges and encourages services to create their own curriculum around their individual context whilst in compliance of the curriculum framework's foundation. Further, goals and learning outcomes illustrate environmental as well as pedagogical provision, and inform educators' planning respectively.

The underpinning vision of Te Whāriki is a perspective of empowerment where children are encouraged and supported in their learning dispositions, rather than achieving performance goals (Peters & Rameka, 2010). Developers of supporting early mathematics resources for educators in New Zealand found in their review of Te Whāriki for its mathematical potential that mathematics was explicit and implicit in the curriculum framework. For example,

> [a]lthough there is a lot of explicit mathematics within the Mana Reo—Communication and the Mana Aotūroa—Exploration strands, mathematics is implicit in all strands; for example, in negotiating fairness, understanding routines, planning and predicting (Mana Whenua—Belonging); and in self-care skills, food preparation, dressing and so on (Mana Atua—Well-being). Through this highlighting exercise, it became clear that mathematics is woven into all the strands (Peters & Rameka, 2010, p. 9).

In light of this, it is therefore interesting to analyse Te Whāriki in relation to how STEM learning is interwoven into the curriculum.

6.3.3 Läroplan För Förskolan

The *Läroplan för Förskolan* (English: "Curriculum for the Preschool") is Sweden's national curriculum framework for ECE. It was first developed and published in 1998 by Skolverket, Sweden's National Education Agency, but has been revised in 2010. Currently, the Läroplan is undergoing a second revision, which demonstrates Sweden's strong commitment to quality ECE: "Sweden considers improving quality through curriculum as a priority" (Taguma et al., 2013, p. 7). The Swedish curriculum framework is a legally binding document anchored in the Education Act (2010:800) that sets out the expectations for all ECE services in Sweden to promote all "children acquiring and developing knowledge and values" (Skolverket, 2010, p. 3). At its foundation, the Läroplan places highest emphasis on Sweden's societal democratic values and human rights. Equity, respect for diversity, offering equal opportunities and inclusive education that leads to lifelong learning are embedded throughout the document.

The Läroplan is structured around its fundamental values, and Goals and guidelines. Goals and guidelines address seven areas:

1. Norms and values;
2. Development and learning;
3. Influence of the child;
4. Preschool and home;
5. Co-operation between preschool class, the school and the leisure-time centre;
6. Follow-up, evaluation, and development; and
7. Responsibility of the head of the preschool.

Despite its binding nature, it offers a flexible framework and guidance for practical implementation, guaranteeing that context, the needs, and ages of the children are respected (Taguma et al., 2013). However, it addresses educators' responsibilities to promote development and learning and to model democratic values to the children. Pedagogical activities and offers to the learning environment must be based on children's interests and needs.

The curriculum framework makes clear references to academic and socioemotional developmental capabilities and skills. From the STEM disciplines, mathematical capabilities are explicated in majority, while science, technology, and engineering are mentioned less. The OECD report for Sweden's review on quality in ECE has criticised the lack of, and suggested that Sweden's curriculum framework could be revised in particular in its "attention to […] the use of ICT" in ECE (Taguma et al., 2013, p. 8):

> The Swedish curriculum includes two goals regarding technology, though not ICT specifically, and states that children should develop their ability to identify technology in everyday life and explore how technology works as well as develop their ability to build, create and construct using different techniques, materials and tools (p. 39).

In relation to societies' increase in use of ICT in everyday life, in private and professional domains, fostering children's ICT skills needs further attention. This chapter will investigate further how STEM has its place in the Läroplan.

6.4 Conceptual Framework

In order to analyse the positioning of STEM in these early childhood curricula documents, a clear articulation of what constitutes "STEM education" is required. To

Table 6.1 Elements of effective STEM education (Murphy et al., 2018)

Element	Description
Capabilities	STEM knowledge and skills, both disciplinary and interdisciplinary
Dispositions	Attitudes and states of mind that support success in STEM education
Educational practices	Intentional actions that educators take to create STEM learning environments
Equity	Recognition of the equity issues in STEM education for female, rural, indigenous, and socioeconomically disadvantaged children
Trajectories	A long-term view of a child's STEM learning journey
Educator capacities	Educators who can deliver high-quality STEM education that develops STEM capabilities and dispositions for all children

facilitate this analysis, we have utilised the six elements of effective STEM education articulated by Murphy et al. (2018). This framework is summarised in Table 6.1, and is described more fully below.

6.4.1 Capabilities

STEM capabilities "include, but are more extensive than, the knowledge and skills associated with the individual STEM disciplines" (Murphy et al., 2018, p. 3). It has been argued that STEM knowledge needs to be conceived of as dynamic and ever changing, and STEM education needs to equip students to source, interpret, and apply evolving understandings (Roth & Van Eijck, 2010). STEM skills are similarly flexible and diverse, and include skills such as adaptability, problem-solving, creativity, critical thinking, and design thinking (Bybee, 2013; Prinsley & Baranyai, 2015).

6.4.2 Dispositions

STEM dispositions are "the attitudes and states of mind that support students achieving success in STEM education and the pursuit of STEM career pathways" (Murphy et al., 2018, p. 3). An extensive body of literature demonstrates that STEM self-concept, the value placed on STEM by the learner, learner autonomy, and relationships with STEM educators and other learners are powerful influences on motivation and academic emotions in STEM education (e.g. Andersen & Chen, 2016; Petersen & Hyde, 2017; Robnett & Leaper, 2013; Wang & Degol, 2013). It is important to note that children's STEM dispositions are influenced by educators from the early childhood years onwards (Patrick et al., 2009).

6.4.3 Educational Practices

STEM educational practices are "intentional actions that schools and educators take to create STEM learning environments that build student STEM capabilities and nurture STEM dispositions" (Murphy et al., 2018, p. 4). While there is debate about the degree to which STEM disciplines should be integrated within educational programs (e.g. Bybee, 2013; Kelley, 2010; Moore & Smith, 2014), there is general agreement that real world inquiry and problem-based learning have a positive impact upon students' STEM capabilities and dispositions (Gee & Wong, 2012; MacLeod, 2013; McDonald, 2016; Ralph, 2015).

6.4.4 Equity

There are known inequities in STEM achievement, particularly for female, rural, indigenous, and socioeconomically disadvantaged students, and effective STEM education must seek to address these inequities (Murphy et al., 2018). Research suggests that educators' curricular and pedagogical choices have a significant impact on the dispositions and academic success of different groups of learning (e.g. Gee & Wong, 2012; Patrick et al., 2009); thus, STEM education must seek to have a positive impact on STEM capabilities and dispositions for *all* learners.

6.4.5 Trajectories

An education trajectory is a long-term view of a student's movement through the education system; thus, a student's STEM trajectory includes their STEM learning journey from early childhood through to senior secondary and beyond (Murphy et al., 2018). International research demonstrates the relationship between early STEM capabilities and later outcomes in STEM (Johnston, 2011; Watts, Duncan, Siegler, & Davis-Kean, 2014). Moreover, transitions between educational settings (e.g. from preschool to school) may impact children's engagement with STEM (Perry, MacDonald, & Gervasoni, 2015; Tytler et al., 2008), and therefore require careful consideration by educators.

6.4.6 Educator Capacities

Effective STEM education requires highly skilled educators who have the ability to deliver integrated, inquiry-based STEM programs that develop STEM capabilities and positive dispositions for all children (Murphy et al., 2018). While there are known challenges, such as the reluctance of some early childhood educators to engage in intentional teaching of STEM disciplines (Lee & Ginsburg, 2009), research has shown that professional development can enhance the confidence and knowledge of educators, bringing about positive impacts upon children's learning and the learning environment (Perry & MacDonald, 2015; McDonald, 2016; Reimers, Farmer, & Klein-Gardner, 2015).

6.5 Method

Three curriculum documents have been analysed in order to make visible the potential for STEM education in early childhood curriculum frameworks. The details of these three curriculum documents are provided in Table 6.2. All three frameworks are public documents available online, in English. The documents were downloaded in September 2018. It should be noted that the three frameworks vary greatly in length, presentation, and style; however, comparison of these features was not an aim of the study.

These three curriculum documents were interrogated using document analysis (Bowen, 2009) guided by a "curriculum analysis key" (Jóhannesson, Norðdahl, Óskarsdóttir, Pálsdóttir, & Pétursdóttir, 2011). Details of the analytic approach are provided below.

Table 6.2 Early childhood curriculum documents

Document title	Author	Year	URL
Belonging, Being, and Becoming: The Early Years Learning Framework for Australia (EYLF)	Australian Government Department of Education, Employment, and Workplace Relations (DEEWR)	2009	https://docs.education.gov.au/system/files/doc/other/belonging_being_and_becoming_the_early_years_learning_framework_for_australia._v5_docx.pdf
Te Whāriki Early Childhood Curriculum	New Zealand Ministry of Education	2017	https://education.govt.nz/assets/Documents/Early-Childhood/ELS-Te-Whariki-Early-Childhood-Curriculum-ENG-Web.pdf
Läroplan för Förskolan ("Curriculum for the Preschool")	Skolverket (Swedish National Agency for Education)	2010	http://www.skolverket.se/om-skolverket/in_english/publications

6.5.1 Document Analysis

Document analysis is a systematic procedure for reviewing or evaluating documents in order to elicit meaning, gain understanding, and develop empirical knowledge (Bowen, 2009). Analytically, this requires finding, selecting, appraising, and synthesising the data contained in the documents (Bowen, 2009), before organising the data into major themes, categories, and examples through content analysis (Labuschagne, 2003). The analysis in this study has been conducted deductively (Labuschagne, 2003), orientated towards testing the theoretical articulation of STEM education established through the use of a "curriculum analysis key" (Jóhannesson et al., 2011). This key, described in the next section, provides predefined codes according to which the textual data contained in the curriculum documents can be analysed and organised (Bowen, 2009). The authors independently coded the three curriculum documents, then held a consensus meeting to discuss coding decisions and develop a consensus view of our findings (Hunt & Walsh, 2011).

6.5.2 Curriculum Analysis Key

In their study of the place of educational for sustainable development within the Icelandic curricula, Jóhannesson et al. (2011) developed a "curriculum analysis key" as a tool for analysis. They described the "key" as outlining the characteristics which reflect the interwoven aspects of their area of focus (sustainable development). Applying this model, this study utilises Murphy et al.'s (2018) elements of effective STEM education as the key for curriculum analysis. The key is extended through the incorporation of key words, informed by the literature and consistent with the framework outlined by Murphy et al. The resulting curriculum analysis key is displayed in Table 6.3.

6.6 Results and Discussion

The Australian, New Zealand, and Swedish curriculum frameworks for early childhood education contain no direct stipulations regarding STEM education. However, implicit in these documents are themes and language consistent with the aims and scope of STEM education. The following discussion presents the results of the content analysis with respect to the curriculum analysis key. It describes the ways in which Murphy et al.'s (2018) six elements of STEM education can be made visible across the three early childhood curriculum frameworks, and presents excerpts from the frameworks as illustrations of the STEM potential embedded in these documents.

Table 6.3 Curriculum analysis key

Element	Key words[a]
Capabilities	Science; technology; engineering; mathematics; numeracy; sustainability; information and communication technologies (ICT); problem solving; critical thinking, design thinking; digital literacy; collaboration; communication; investigating; experimenting; hypothesising
Dispositions	Curiosity; creativity; persistence; motivation; self-efficacy; engagement; aspiration; confidence; resilience, mind-set
Educational practices	Inquiry; investigation; integration; real-world; problem-based learning; project-based learning; digital learning
Equity	Gender; indigeneity; culture; rural/remote; socioeconomic status
Trajectories	Transitions; learning journey; continuity; challenge; prior learning
Educator capacities	Content knowledge; pedagogical content knowledge (PCK); modelling; professional development/learning

[a]The key words listed here were taken to include any words that may have the key word as their root (e.g. “investigation”, “investigating”, “investigate”)

6.6.1 Capabilities

All three curriculum frameworks place an emphasis on outlining the capabilities developed by children, and these include STEM capabilities—encompassing both conceptual knowledge, and skills and processes. It is in relation to this element that all three documents are most explicit in the reference to STEM ideas, and it is arguably the Läroplan för Förskolan that is most direct in this respect. For example, the Swedish curriculum includes goals for children’s learning such as:

- Develop their understanding of space, shapes, location, and direction, and the basic properties of sets, quantity, order, and number concepts, also for measurement, time and change;
- Develop their ability to use mathematics to investigate, reflect over, and test different solutions to problems raised by themselves and others;
- Develop their ability to distinguish, express, examine, and use mathematical concepts and their interrelationships;
- Develop their mathematical skill in putting forward and following reasoning;
- Develop their interest and understanding of the different cycles in nature, and how people, nature, and society influence each other;
- Develop their understanding of science and relationships in nature, as well as knowledge of plants, animals, and also simple chemical processes and physical phenomena;
- Develop their ability to distinguish, explore, document, put questions about and talk about science;
- Develop their ability to identify technology in everyday life, and explore how simple technology works; and

- Develop their ability to build, create, and construct using different techniques, materials, and tools (Skolverket, 2010, p. 10).

It is evident in these excerpts that knowledge and skills associated with the disciplines of mathematics, science and technology are explicitly named and described in this ECE curriculum framework. Engineering is less visible; though, can be extrapolated through statements such as “build, create, and construct”.

Explicit STEM knowledge and skills are also apparent in the EYLF (DEEWR, 2009) and these are evident across Learning Outcomes 2–5; though, most extensively within Outcome 4. For example:

Outcome 2:

- Demonstrate an increasing knowledge of, and respect for natural and constructed environments;
- Explore, infer, predict, and hypothesise in order to develop an increased understanding of the interdependence between land, people, plants, and animals;
- Explore relationships with other living and non-living things and observe, notice, and respond to change; and
- Develop an awareness of the impact of human activity on environments and the interdependence of living things (p. 29).

Outcome 3:

- Demonstrate spatial awareness and orient themselves, moving around and through their environments confidently and safely; and
- Manipulate equipment and manage tools with increasing competence and skill (p. 32).

Outcome 4:

- Apply a wide variety of thinking strategies to engage with situations and solve problems, and adapt these strategies to new situations;
- Create and use representation to organise, record and communicate mathematical ideas and concepts;
- Make predictions and generalisations about their daily activities, aspects of the natural world and environments, using patterns they generate or identify and communicate these using mathematical language and symbols;
- Manipulate objects and experiment with cause and effect, trial and error, and motion;
- Use the processes of play, reflection and investigation to solve problems;
- Manipulate resources to investigate, take apart, assemble, invent and construct;
- Experiment with different technologies; and
- Use information and communication technologies (ICT) to investigate and problem solve (pp. 35–37).

Outcome 5:

- Demonstrate an increasing understanding of measurement and number using vocabulary to describe size, length, volume, capacity and names of numbers;

- Use language to communicate thinking about quantities to describe attributes of objects and collections, and to explain mathematical ideas;
- Begin to understand key numeracy concepts and processes;
- Begin to sort, categorise, order, and compare collections and events and attributes of objects and materials, in their social and natural worlds;
- Use ICT to access images and information, explore diverse perspectives, and make sense of their world; and
- Use ICT as tools for designing, drawing, editing, reflecting, and composing (pp. 40–44).

Similar to the Swedish Läroplan, the disciplines of mathematics and technology are explicitly named within the EYLF outcomes. Science is not explicitly identified; though, is evident through statements referring to scientific knowledge (e.g. understanding environments, living things, interdependence), as well as indication of the scientific method (e.g. infer, predict, hypothesise, generalise). As with the Läroplan, engineering and design thinking can be extrapolated through reference to *taking apart, assembling, inventing,* and *constructing*.

Structurally, New Zealand's Te Whāriki (Ministry of Education, 2017) is similar to the EYLF in its organisation around five strands and their aspirations for children's learning and development. STEM capabilities are evident within four of these five strands, for example:

Strand 2:

- Skills in caring for the environment, such as cleaning, fixing and gardening (p. 32).

Strand 3:

- Awareness of the strategies they use to learn new skills and generate and refine working theories; and
- Ability to use memory, perspective taking, meta-cognition and other cognitive strategies for thinking, and ability to make links between past, present, and future (p. 37).

Strand 4:

- An understanding that symbols can be "read" by others and that thoughts, experiences, and ideas can be represented as words, pictures, numbers, sounds, shapes, models, and photographs in print and digital formats;
- Familiarity with numbers and their uses by exploring and observing their use in activities that have meaning and purpose; and
- Ability to explore, enjoy and describe patterns and relationships related to quantity, number, measurement, shape, and space (p. 42).

Strand 5:

- Ability and inclination to cope with uncertainty, imagine alternatives, make decisions, choose materials, and devise their own problems;

- Confidence in exploring, puzzling over, and making sense of the world, using such strategies as setting and solving problems, looking for patterns, classifying, guessing, using trial and error, observing, planning, comparing, explaining, engaging in reflective discussion, and listening to stories;
- Recognition of different domains of knowledge and how they relate to understanding people, places, and things;
- Curiosity and the ability to inquire into research, explore, generate and modify working theories about the natural, social, physical, spiritual and human-made worlds; and
- A sense of responsibility for the living world and knowledge about how to care for it (p. 47).

Te Whāriki clearly differs from the other two frameworks in that the STEM disciplines are not specifically identified among the learning outcomes, nor is there an emphasis on the content knowledge associated with these disciplines. Rather, STEM capabilities are most evident in outcomes representing the *skills* and *processes* of STEM (e.g. exploring, observing, comparing, and explaining).

A key similarity across the three frameworks is their focus on sustainability and care for environments, with statements such as: "understand and respect the natural environment and the interdependence between people, plants, animals and the land" (EYLF, p. 14); "respect for our shared environment" (Läroplan, p. 3); and "support [children] to fulfil their responsibilities as kaitaki[3] of the environment" (Te Whāriki, p. 48) evident among the explanatory text for each curriculum. In doing so, the three documents foreground the knowledge and skills required for children to become careful custodians of the environments in which they live.

6.6.2 Dispositions

As for STEM capabilities, all three curriculum documents emphasise the development of children's learning dispositions, and embedded within this discourse are dispositions that are beneficial for STEM learning. Indeed, a fundamental value of the Läroplan is that "the child's curiosity, initiative and interests should be encouraged and their will and desire to learn should be stimulated" (p. 5); while Te Whāriki is underpinned by a vision that children are "competent and confident learners and communicators" (p. 2). Similarly, Outcome 4 of the EYLF is *Children are confident and involved learners*; a key component of which is that "Children develop dispositions for learning such as curiosity, cooperation, confidence, creativity, commitment, enthusiasm, persistence, imagination and reflexivity" (p. 34). All three curricula provide specific aspirations for children's learning dispositions. For example, the goals of the Läroplan state that the preschool should strive to ensure that each child:

[3] "Kaitaki" is a Māori word meaning "trustee, custodian, guardian, protector" (Ministry of Education, 2017, p. 66).

- Develop their curiosity and enjoyment, as well as their ability to play and learn; and
- Develop self-autonomy and confidence in their own ability (p. 9).

STEM dispositions are also evident across Strands 2–5 of Te Whāriki; though, predominantly within Strand 5:

Strand 2:

- Interest and pleasure in learning about the wider; unfamiliar world (p. 32).

Strand 3:

- A positive learner identity and a realistic perception of themselves as being able to acquire new interests and capabilities (p. 37).

Strand 4:

- Recognition that numbers can amuse, delight, comfort, illuminate, inform and excite (p. 42).

Strand 5:

- An understanding that trying things out, exploring, playing with ideas and materials and collaborating with others are important and valued ways of learning;
- Ability to pursue an interest or a project for a sustained period of time; and
- Curiosity about the world and the ability and inclination to share interests with others (p. 47).

There is similar prevalence of STEM dispositions in the EYLF, with these evident within Learning Outcomes 1, 3, and 4. For example:

Outcome 1:

- Confidently explore and engage with social and physical environments through relationships and play;
- Be open to new challenges and discoveries;
- Increasingly co-operate and work collaboratively with others;
- Take considered risk in their decision-making and cope with the unexpected; and
- Persist when faced with challenges and when first attempts are not successful (pp. 21–22).

Outcome 3:

- Seek out and accept new challenges, make new discoveries, and celebrate their own efforts and achievements and those of others; and
- Make choices, accept challenges, take considered risks, manage change and cope with frustrations and the unexpected (p. 31)

Outcome 4:

- Express wonder and interest in their environments;
- Are curious and enthusiastic participants in their learning;

- Follow and extend their own interests with enthusiasm, energy, and concentration;
- Persevere and experience the satisfaction of achievement; and
- Persist even when they find a task difficult (p. 34).

It can be seen that the STEM dispositions of curiosity, confidence, persistence, interest, and enjoyment are common across the three frameworks. Coupled with the learning outcomes focusing on STEM capabilities described in Sect. 8.6.2, these dispositions enhance the likelihood of young children experiencing positive STEM education and developing a positive STEM identity.

6.6.3 Educational Practices

Within the curriculum documents, STEM educational practices can be extrapolated from examples that are given around the opportunities educators should offer to children. All three frameworks advocate for inquiry, investigation and exploration, which are well-established in the STEM education literature as powerful educational practices for STEM learning. For example, Strand 5 of Te Whāriki is "Exploration" which advocates for learning through active exploration of the environment. Similarly, the Läroplan states that "a sense of exploration, curiosity and desire to learn should form the foundations for preschool activities" (p. 9). Inquiry practices permeate Outcome 4 of the EYLF, which is founded on guidance such as "children use processes such as exploration, collaboration and problem solving across all aspects of curriculum"; "inquiry processes [are] necessary for lifelong learning"; and "children develop understandings of themselves and their world through active, hands-on investigation" (p. 33).

Across the frameworks, connections between learning experiences and children's everyday lives, environments and communities are emphasised—reinforcing the notion of "real world" in STEM educational practices. For example, the EYLF describes the following educational practices that can be employed by educators in support of the learning outcomes:

Outcome 2:

- Build connections between the early childhood setting and the local community;
- Provide opportunities for children to investigate ideas, complex concepts, and ethical issues that are relevant to their lives and their local communities (p. 26)

Similarly, Te Whāriki emphasises real-world connections in its learning outcomes:

Strand 2:

- An ability to connect their learning in the ECE setting with experiences at home and in familiar cultural communities and a sense of themselves as global citizens; and
- Knowledge about features of the local area, such as a river or mountain (this may include their spiritual significance (p. 32).

Real-world connections are also highlighted in the Läroplan, which emphasises the need for the educational team to "give children the opportunity to become familiar with their own immediate environment, and those functions which are important in daily life" (p. 11).

Building on this real-world connectivity is an emphasis on educational practices focusing on sustainability and responsibility for the environment. As described in Sect. 8.6.1, knowledge about and for environmental sustainability is a key STEM capability developed in all three curricula. For example, the Läroplan states that the educational team should give children the opportunity of understanding how their own actions can have an effect on the environment" (p. 11). EYLF Outcome 2 encourages the following educational practices:

Outcome 2:

- Find ways of enabling children to care for and learn from the land;
- Share information and provide children with access to resources about the environment and the impact of human activities on environments;
- Embed sustainability in daily routines and practices; and
- Look for examples of interdependence in the environment and discuss the ways the life and health of living things are interconnected (p. 29).

In summary, there are a range of educational practices embedded in the three frameworks which support the development of STEM capabilities and dispositions.

6.6.4 Equity

Equity is an underlying principle in all three curriculum frameworks, although it is not mentioned specifically for STEM learning. However, examples of respecting diversity and offering equal opportunities are given in general. Inclusive education is promoted in all three documents. Te Whāriki describes itself as "an inclusive curriculum—a curriculum for all children" (p. 13); one which "holds the promise that all children will be empowered to learn with and alongside others by engaging in experiences that have meaning for them" (p. 13). Te Whāriki has a particular emphasis on cultural inclusion and the valuing of Māori and Pasifika perspectives.

The Läroplan is based upon the fundamental values of democracy, equity, and ethics. The Läroplan is distinct from the other two frameworks in that it pays particular attention to gender equality. The guiding narrative of the curriculum states that "the equal value of all people, equality between the genders, as well as solidarity with the weak and vulnerable are all values that the preschool should actively promote in its work with children" (p. 3). Moreover, "girls and boys in the preschool should have the same opportunities to develop and explore their abilities and interests without having limitations imposed by stereotyped gender roles" (p. 4). This is an important finding given the known challenges around girls' participation in STEM and the influence of stereotyping.

The EYLF has as one of its five underpinning principles, “High expectations and equity”—a commitment to equity and the belief “in all children’s capacities to succeed, regardless of diverse circumstances and abilities” (p. 13). Another of the five principles is “Respect for diversity”, which advocates for honouring the diverse histories, cultures, languages, and traditions of children and families. Particular attention is drawn to promoting Aboriginal and Torres Strait Islander ways of knowing and being.

Given the known challenges around equity and participation in STEM, to have such aspirations underpinning curricula that contain many opportunities for STEM learning is very encouraging indeed.

6.6.5 Trajectories

Trajectories receive attention in all three frameworks by discussing transitions and/or learning pathways. For example, the Läroplan states that “the preschool should lay the foundations for lifelong learning” (p. 4), while the EYLF aims to “extend and enrich children’s learning from birth to five years and through the transition to school” (p. 5). Both the EYLF and Te Whāriki provide specific guidance in relation to the transition from early childhood education settings to school settings, and both documents include a section on supporting pathways to school. However, Te Whāriki is the only curriculum that provides specific guidance in relation to STEM—the transitions section of the curriculum contains explicit consideration of science and mathematics and the connections between Te Whāriki and the New Zealand Curriculum for schools. Educators are encouraged to “recognise and show where and how children’s early learning connects with the key competencies, values and learning areas of *The New Zealand Curriculum* and *Te Marautanga o Aotearoa*[4]” (p. 58).

6.6.6 Educator Capacities

Educator capacities can be understood as an underlying consideration for all learning outcomes in the curricula, and all three curriculum frameworks address educators’ responsibilities to promote learning. Key aspects are observing, documenting, and assessing children’s learning; planning for learning; and providing learning environments. The Läroplan provides specific guidance in relation to STEM, for both the individual educators and for the educational team as a whole:

Preschool teachers are responsible for work in the group of children taking place so that children:

- Receive new challenges that stimulate enjoyment in learning new skills, experiences, and knowledge;

[4] *Te Marautanga o Aotearoa* is the curriculum for Māori-medium schools in New Zealand.

- Are stimulated and challenged in their mathematical development; and
- Are stimulated and challenged to develop their interest in science and technology (p. 11).

The work team should:

- Challenge the curiosity of children and their growing understanding of language and communication, mathematics, as well as science and technology; and
- Give children the opportunity to develop their ability to communicate, document, and describe their impressions, experiences, ideas, and thinking processes by means of words, concrete materials, and pictures, as well as aesthetic and other forms of expression (p. 11).

STEM-related guidance for educators is also provided in the EYLF. Indeed, a key element of educator practice is *intentional teaching*, which describes the capacities of educators as follows:

> They actively promote children's learning through worthwhile and challenging experiences and interactions that foster high-level thinking skills. They use strategies such as modelling and demonstrating, open questioning, speculating, explaining, engaging in shared thinking and problem solving to extend children's thinking and learning (p. 15).

Moreover, Outcomes 2–4 describe the personal actions that educators can take, and attributes they can possess, to promote STEM learning, for example:

Outcome 2:

- Model respect, care, and appreciation for the natural environment; and
- Consider the nature of children's connectedness to the land and demonstrate respect for community protocols (p. 29).

Outcome 3:

- Challenge and support children to engage in and persevere at tasks and play;
- Build upon and extend children's ideas; and
- Maintain high expectations of each child's capabilities (p. 31).

Outcome 4:

- Respond to children's displays of learning dispositions by commenting on them and providing encouragement and additional ideas;
- Encourage children to engage in both individual and collaborative explorative learning processes;
- Model inquiry processes, including wonder, curiosity, and imagination, try new ideas and take on challenges;
- Plan learning environments with appropriate levels of challenge where children are encouraged to explore, experiment, and take appropriate risks in their learning;
- Recognise mathematical understandings that children bring to learning and build on these in ways that are relevant to each child;
- Provide experiences that encourage children to investigate and solve problems;

- Provide opportunities for involvement in experiences that support the investigation of ideas, complex concepts and thinking, reasoning, and hypothesising;
- Model mathematical and scientific language;
- Join in children's play and model reasoning, predicting and reflecting processes and language;
- Listen carefully to children's attempts to hypothesise and expand on their thinking through conversation and questioning;
- Support children to construct multiple solutions to problems and use different ways of thinking;
- Draw children's attention to patterns and relationships in the environment and in their learning;
- Introduce appropriate tools, technologies, and media and provide the skills, knowledge, and techniques to enhance children's learning; and
- Develop their own confidence with technologies available to children in the setting (pp. 34–37).

Reflective practice is highlighted in all three frameworks, and Te Whāriki provides some reflective questions concerning STEM learning, for example:

- What opportunities might kaiako[5] offer children to connect to, respect and care for Papatūānuku[6]?
- How might kaiako help children and families learn more about the local area?
- In what ways can kaiako support children to take care of or become kaitiaki of this place?
- What types of literacy and numeracy opportunities are offered to children that will support knowledge of symbols and learning of concepts about print and mathematics?
- How might children be encouraged to connect with and care for their worlds in ways that are responsive to Māori values?
- How might children explore the natural and living worlds while remaining respectful of the cultural beliefs and worldviews of others?
- In what ways can real tools (such as gardening tools, saws, and microscopes) be used confidently for exploration that leads to meaningful learning and sense making?
- How might kaiako encourage children to see a range of strategies they might adopt for exploration, thinking, reasoning, and problem-solving?
- What domain knowledge would help kaiako to recognise, respond to, and extend children's generation and refinement of working theories?
- How might kaiako create and model a cultural of inquiry amongst children?
- What opportunities exist for children to participate in longer-term projects that support the development of their working theories? (pp. 35–50).

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[5]"Kaiako" is a Māori word meaning "teacher(s)" (Ministry of Education, 2017, p. 66).

[6]"Papatūānuku" is a Māori word meaning "Earth" or "Earth mother" (Ministry of Education, 2017, p. 66).

All three frameworks also elaborate on professional development, educator learning and training; for example, the "Ongoing learning and reflective practice" principle underpinning the EYLF (p. 13). These aims are general and not specific to STEM disciplines; however, taken in conjunction with outcomes focusing on children's STEM capabilities and dispositions, this becomes powerful for children's STEM learning opportunities.

6.7 Conclusion

In this chapter, we have shifted the argument for STEM education from nations' need for STEM literate workforce to compete on the global market to children's right to education, including STEM content knowledge and interdisciplinary skills. This right has high importance in light of the sustainable development goals, raising awareness of STEM literacy for a sustainable future. STEM skills are, and continue to be, life-essential for the youngest generation of active citizens growing up and living in a digitised world. Therefore, we agree with Cohrssen and Page (2016) and extend their ethical argumentation for mathematics education to all STEM disciplines. National early childhood curriculum frameworks have a great deal of potential to make STEM education accessible from the early years. Our analysis of the EYLF, Te Whāriki, and the Läroplan för Förskolan has made visible the STEM learning opportunities embedded within these curriculum frameworks, and has articulated how these frameworks can act as vehicles for effective STEM education in the early years. However, further research is required to examine how educators can translate, and meet, their expected responsibilities in relation to effective STEM education.

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Chapter 7
Supporting and Scaffolding Early Childhood Teachers in Positive Approaches to Teaching and Learning with Technology

Jennifer Munday, Natalie Thompson and Michael McGirr

Abstract Quality early childhood education in the areas of science, technology, engineering and mathematics (STEM) is increasingly recognised as an important component of a contemporary education for all children. In order for this to happen, teachers need to be well prepared to teach all elements of STEM in early childhood contexts. While we have seen progress within many areas of STEM in early childhood, there are fears that early childhood teachers remain unsure of how to integrate technology meaningfully within an early childhood programme. We live in an era characterised by increasingly prevalent digital tools and rapid technological change. Many early childhood teachers are reported to be nervous or negative about having the knowledge to use digital technology with young children. This attitude impacts their confidence and ability to design high-quality educational experiences for young children. The aim of this chapter is to present the results of a small qualitative study that explored the responses to an online teacher education subject that was designed to influence early childhood teachers' beliefs and confidence using digital technologies in early childhood settings. The students in this graduate entry degree programme were already early childhood educators and consistently entered the programme with fear of, or negative attitudes towards, the role of digital technologies in early childhood settings. The learning content and the assessment tasks were based on constructivist theories of learning where the early childhood educators were supported to build knowledge and confidence using digital technologies through the active and reflective experience of using digital technologies in their own online learning. Data is presented to show the changes in confidence and beliefs of the participants after undertaking the course of study.

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7.1 Introduction

> We are no longer living in a world where it's practical to disregard or avoid 'screen time.' Children of today are being born into the digital era, and they need to be prepared for the digital life that lay ahead for them – whether that be web-based study, online shopping, or chatting virtually with family and friends (Woodland 2017, para 5).

> I am an educator and person in general that can get quite overwhelmed with new technology but I also understand that it has an important role to play and allows us access to so much information that can enhance our learning experiences (ECEs 1, 2018 student forum posting).

The increasing recognition and understanding that learning and living in the twenty-first century requires new skills and new ways of thinking has captured our interests for some time. One of the most powerful movements to come from this thinking is the prioritising of STEM education and the importance of understandings relating to science, technology, engineering and mathematics to be developed across the breadth of the learning continuum, particularly the early years (Kumtepe & Genc-Kumtepe, 2015). This chapter focuses on the T in STEM and more specifically the integration of digital technologies in meaningful and appropriate learning experiences with young children. While much of the literature emphasises the importance of an integrated approach to STEM, technology is seen as "an indispensable component" (Dogan & Robin, 2015, p. 77) but a construct that often sits uncomfortably with pre-established views of early childhood education (ECE) (Edwards, 2013). Preparing early childhood teachers to comfortably use digital technologies in meaningful and enabling ways is of critical importance. Competence using digital technologies is widely argued to be essential for success in contemporary society (Warschauer & Matuchniak, 2010) and an important element of any ECE programme.

The role of digital technologies in ECE is complex and problematic. The tools of technology advance very quickly. More than 5 billion people in the world use mobile phones with 2.5 billion of them using smartphones, thereby carrying a small computer on their person everywhere they go (Shaulova, 2019). It is beyond the time when these tools of technology can be ignored, and as highlighted in Woodland (2015, para. 5) quote above, educators need to be effectively and knowledgeably incorporating the use of different digital technologies into the learning experiences of young children. The ubiquity of the smartphone can lead to a perception that digital technologies will be abundant in early childhood education services and already being used productively with young children. However, as is hinted at in the second quote above from an ECE university student (ECEs 1, 2018 student forum posting) it is still the case that ECE teachers can be nervous about technology and hesitant about using new digital technologies with young children.

Even though quantitative studies undertaken in Australia and internationally show that ECE teachers are becoming more confident in the use of technology (Nikolopoulou & Gialamas, 2015; Hatzigianni & Kalaitzidis, 2018), it appears to be a slow progression to confidence for many of them. This slow move to confidence is apparent in ECE educators entering the Educational Technology course which forms part of a graduate entry Bachelor of Education (Birth to 5 years) degree programme at Charles Sturt University, a regional university in New South Wales, Australia. Ever since the initial intake over a decade ago, there has been a reluctance for online students to take the course as an elective due to a fear and insecurity in personal abilities and attitudes towards technology. This fear has been documented over a number of years formally through subject experience surveys and informally through email and face to face conversations between ECE students[1] and academic teachers. These experiences prompted the academic teaching team to design a small qualitative study that sought to answer "How can ECE teachers be supported and scaffolded in the use of, and teaching with, technology"? In other words, "How can we help ECE teachers with a fear or negative attitude towards technology change their beliefs and become confident users and teachers of technology"?

7.2 Literature Review

7.2.1 Digital Technologies in ECE

It is well established that digital technologies are becoming increasingly prevalent and important in the lives of young children (Bird & Edwards, 2015; National Association for the Education of Young Children and the Fred Rogers Centre for Early Learning and Children's Media, 2012). There is a raft of research data available that describes this prevalence. In Australia, for instance, it is reported that 99% of households with children under 15 use mobile or smartphones to access the Internet (Australian Bureau of Statistics, 2018) with 13% of children under the age of 6 reported to use a smartphone, and 17% a tablet device, every day of the week (Royal Children's Hospital, 2017). According to a report on computer gaming in Australia conducted by the Interactive Games & Entertainment Association (IGEA), 97% of homes with children have devices used for playing computer games and 36% of children aged 1–4 play computer games (IGEA, 2018). International research indicates that Australian statistics are comparable or even higher than the pervasiveness of digital technologies in other Anglophone countries. In the USA, for example, 98% of children under the age of 8 have access to a tablet device with 35% of all screen time in children under 8 coming from a mobile device (Rideout, 2017). In the UK, almost 75% of young 3–5 years have a touch screen device in their homes (Formby, 2014) with 12% of children in this age group regularly accessing the Internet (Ofcom, 2013). These statistics offer an indication—a partial picture—of the pervasiveness of digital technologies. Beyond these figures, we know that children are immersed in diverse worlds of digital cameras, digital music and digital selections of meals in restaurants (Chassiakos, Radesky, Christakis, Moreno & Cross, 2016). Even if they don't own,

[1]Please note, since there can be confusion in writing about higher education 'students' as well as the 'students' from the higher education students own classrooms, the higher education students will be referred to as Early Childhood Education students and abbreviated to ECEs throughout the chapter. When referring to the children they are teaching we will say 'children' or 'students.'

or regularly use, a device, they observe as their family members and friends fluidly incorporate an expanding range of digital tools into everyday life (Plowman, 2015).

Despite the ubiquity of digital technologies in children's everyday lives, debates remain about the appropriateness of their inclusion in ECE settings. For example, House (2012), referring to the philosophy of Rudolph Steiner, argues that digital technologies in EC settings risks a type of "developmental violence" (p. 106) due to their inability to allow holistic mind–body–soul–spirit development. Others consider that these tools diminish young children's imagination (Singer & Singer, 2009), disrupt child-centred pedagogy (Morgan, 2010), replace traditional and more valuable types of play (Cristia & Seidl, 2015) and decrease physical activity (Cordes & Miller, 2000). These views have been widely contested and there now exists a growing body of literature that documents a range of ways in which digital technologies have been used meaningfully, and appropriately, in ECE settings (Lentz, Seon & Gruner, 2014). For example, it is argued that high-quality experiences with digital technologies offer a range of opportunities for the development of social interaction (Wohlwend, 2015), academic skills (Levy & Sinclair, 2017) and when connected to the Internet offer access to interesting and current sources of information that promote open-ended inquiries (Thorpe et al., 2015). Arrow and Finch (2013) argue that the appropriate use of digital devices in the early years provides meaningful connections between home and educational settings and supports a strengths-based philosophy where young children's experiences with technologies are valued and supported. Further, competence with digital technologies is considered "crucial to enabling full social and economic participation" (Warschauer & Matuchniak, 2010, p. 179) and are therefore relevant to education across all ages (Hatzigianni, 2018).

As a result of this research, it is now widely accepted that digital technologies are a necessity in ECE settings (Yelland, 2011). Early Childhood Australia, a leading early childhood advocacy organisation in Australia, recently published a discussion paper on the role of digital technologies in ECE (Edwards, Straker & Oakey, 2018), which acknowledges that while our understandings are still developing, digital technologies have a legitimate and important place in these settings. In 2012, the National Association for the Education of Young Children and the Fred Rogers Centre for Early Learning and Children's Media (NAEYC) identified ECE teachers as having significant potential to provide equitable access to appropriate experiences with digital technologies for all children. Stemming from the growing significance of digital technologies in society and the economy, particularly in relation to future job opportunities (Warschauer & Matuchniak, 2010), this recommendation highlights the potential of educators to address the "digital divide" between the haves and have-nots of enabling digital experiences (Yelland & Neal, 2013).

Consequently, the inclusion of digital technologies in ECE settings is argued to be a matter of social justice (Warschauer & Matuchniak, 2010). It is increasingly seen as an educational right (Yelland & Neal, 2013) and specified in policy and curriculum documents around the world such as the Early Years Learning Framework (DEEWR, 2009) in Australia which encourages children to resource their own learning by connecting with people, places, technologies and natural materials (Outcome 4) and become effective communicators by expressing ideas and making meaning using a range of media as well as using information and communication technologies to access information, investigate ideas and represent their thinking (Outcome 5).

7.2.2 ECE Teachers' Practices and Attitudes

Despite their increasing pervasiveness, there remains widespread variation on how digital technologies are used in ECE settings. It seems that many educators remain unsure of how best to incorporate digital technologies into their pedagogy (Thorpe et al., 2015), with personal beliefs or attitudes towards digital technologies (Blackwell, Lauricella, & Wartella, 2016; Lindahl & Folkesson, 2012; Thorpe et al., 2015) and confidence in tool use (Blackwell et al., 2013) both found to contribute significantly to educational practice. Although recent research has begun to show that confidence using digital tools is beginning to grow among ECE educators, it remains most pronounced in educators' personal usage (Hatzigianni & Kalaitzidis, 2018). For instance, Arrow and Finch (2013) found that the educators they surveyed confidently used digital technologies in their personal lives and possessed valuable knowledge about contemporary digital tools but their views of ECE, particularly in relation to development in literacy, favoured traditional print-based experiences. Again, Palaiologou (2016) found that despite a high level of confidence in using digital tools, such as mobile phones, in their personal lives, some educators lacked the confidence to use these tools in developmentally appropriate ways particularly in regard to their commitment to philosophies of play-based learning. It seems there remains a disconnect between educators' personal usage as well as the intentions of policy documents and the integration of digital technologies in ECE with many researchers calling for more specific teaching of the appropriate use of digital technologies in professional development programmes and teacher education courses (Thorpe et al., 2015) that are designed to challenge preconceived beliefs and attitudes (Blackwell et al., 2013).

It has been argued that to challenge beliefs and attitudes, educators within training organisations need to showcase, and model, the pedagogical integration of technology and provide supportive environments for ECEs to share their beliefs, attitudes and perceived abilities with each other (Tondeur et al., 2012). In particular, in a study that investigated the foundations of ECE educators' beliefs and integration of digital technologies, Mertala (2017) found that the specific ways digital technologies are modelled to the ECE educators had a significant influence on their beliefs and usage. Mertala (2017) and also Zabatiero, Mantilla, Edwards, Danby, and Straker (2018) argue that it is therefore important that the models provided in teacher education courses reflect appropriate and research-based practice.

A growing number of studies suggest that digital technologies are most effectively integrated in ECE settings through student-centred pedagogy (Blackwell, et al., 2016; Li & Ma, 2010) "with student interests and abilities guiding the content, pace and learning activities"(Blackwell, Lauricella & Wartella, 2016, p. 59). This is an active type of learning—a learning by doing, where the individual student learns by building on their own knowledge and experiences (Howell, 2013) which has clear connections to a constructivist view on learning. According to Hatzigianni & Kalaitzidis (2018), many constructivists view "technology as a device, a tool to expand children's learning, rather than something to be used in a rote drill/skill type activity" (p. 885). Constructivism provides a useful framework for thinking about the ways in which digital technologies can be used appropriately in ECE settings. It also provides a theoretical base for thinking about the pedagogical integration of digital technologies in higher education.

7.2.3 Using Digital Technologies in Higher Education

The increasing prevalence of digital technologies has opened up new opportunities in higher education. In particular, these technologies have enabled the rapid growth of online education which opens opportunities for designing a range of innovative learning experiences to a greater diversity of students (Steel & Andrews, 2012). With an expanding repertoire of digital tools available, it remains that technologies need to be "fit for purpose" by being aligned to "educational objectives, as well as the learning needs of [the] target audience" (King et al., 2014, p. 111). As previously stated, the educational objectives of this course of study relate to ECEs' future integration of digital tools in their own teaching. Digital technologies were both the content of study and the method of delivery which provides an interesting case to examine the different approaches to digital integration. For instance, in a study of 127 Australian academics involved in initial teacher education (ITE), Reyes, Reading, Doyle and Gregory (2017) found a disconnect between how these lecturers used digital technologies and how they taught about using digital technologies. Given the expectation that graduate teachers be confident and capable users of technology (Australian Institute for Teaching and School Leadership [AITSL], 2011) and an apparent correlation between educators' integration of digital technologies and the experiences they had in their teacher education courses (Tondeur et al., 2012), consideration must be given to the pedagogical integration of digital technologies in higher education by academic teachers.

In thinking about how the ECEs in this study might be supported, and scaffolded, in their own use of, and their teaching with, digital technologies, the course designers remained guided by the framework of constructivism. Summarised by Jonassen, Howland, Marra and Crismond (2008), constructivism, or "meaningful learning, will result when technologies engage learners in the following: knowledge construction, not reproduction; conversation, not reception; articulation, not repetition; collaboration, not competition; reflection, not prescription." (p. 10). Branscombe et al. (2014) explain more clearly:

> Constructivism is a theory of knowing that emphasizes the role each person plays in constructing his or her own knowledge rather than absorbing knowledge directly from the environment. The focus is on children's creation of knowledge rather than on their repeating what others consider important… Each individual uses knowledge she has already constructed

and relates new information to that knowledge. In the process, she creates knowledge for herself. (p. 9)

A constructivist model has been successfully applied elsewhere to influence ECE teachers' confidence and pedagogical use of digital technologies, for instance, Highfield and Papic (2015) demonstrate how digital technologies can be used to create a digital community of geographically diverse leaners, in support of the constructivist's commitment to joint construction of knowledge (McDonald & Reushle, 2002). Similarly, Highfield, De Goia and Lane (2014) demonstrate how creating opportunities for ECEs to use digital technologies in authentic ways, where they are encouraged to explore and understand the real-world application of different technologies, can lead to increasingly effective integration of digital technologies in their future classrooms.

Encouraged by these results, the researchers sought to explore how the constructivist principles that guided the design of the learning materials, and the approach to supporting and scaffolding, impacted ECEs' beliefs, attitudes and confidence in their perceived willingness and intention to use digital technologies in their future ECE classrooms.

7.3 Background

Charles Sturt University (CSU) is an Australian multi-campus and geographically dispersed Higher Education provider. While most University campuses are in the state of New South Wales, CSU has study centres in other states and overseas. CSU prides itself on being a *University for the professions*, emphasising its role in supporting, developing and researching professional practice at all levels. CSU is one of the largest providers of distance education in Australia and students are drawn from a wide range of geographical areas, across Australia and overseas.

In 2017 and 2018 two cohorts of students enrolled in this Educational Technology course: an online-only cohort, and a face-to-face cohort that received a blended model of subject delivery through a series of face-to-face workshops combined with the online learning materials.

The online ECEs cohort consisted mostly of people already working in the field, with only a few who are moving directly from undergraduate study to graduate entry. As Early Childhood Educators who often feel professionally isolated in their work, they are keen to create a community of learners to act as a support network in the online space. The face-to-face ECEs have completed the equivalent of a college diploma (2 years of study), and are continuing their study to complete a Bachelors Degree. The teaching facilities are in urban Sydney, Australia's largest city, and the cohort includes international students. The cultural backgrounds of the face-to-face cohort are diverse, which adds richness and depth to student collaboration and discussion. The online Learning Management System (LMS) is a Blackboard classroom where both groups can be blended to access discussion boards, learning modules, assessment outlines and synchronous and asynchronous online meetings.

The ECEs cohorts ranged in age from twenty to sixty, with the average age being thirty-three, (CSU, Office of Strategic Planning and Information). Across both cohorts, there were sixty-five enrolments in 2017 and thirty-four enrolments in 2018.

7.4 The Course of Study

The assessment tasks and learning activities in the course of study were based on constructivist principles where the students "constructed" their own knowledge about using digital technologies in educationally appropriate ways by actually using digital technologies in these ways. The first assessment task was introduced in the first weeks of study and was a scaffolded investigation and presentation on a topic related to the role of digital technologies in ECE. ECEs were able to choose a topic that was meaningful for them and then presented their investigation with both cohorts of students using an online conferencing platform. Generally, academics use web conferencing tools in distance teaching to conduct lectures and tutorials (Li, 2014). Higher education students attend these virtually, in order to engage in experiences similar to on-campus students. In the Technology course of study we have "flipped" this process from the instructor being the knowledge holder, by having the ECEs present their findings inside the online environment to their peers (Ozdamli & Asiksoy, 2016).

During the scaffolding process of their first assessment task ECEs engaged in a series of online exchanges with their academic teachers and peers using tools such as Wiki, forum posting and an online conferencing tool. The purpose of these exchanges was to support each of the ECEs to choose an appropriate topic for investigation. ECEs were able to receive feedback and advice from peers, and the academic teacher, to help them focus this question for their investigation (Aymerich-Franch & Fedele, 2014).

After the presentations, the ECEs were involved in more knowledge building and sharing tasks, including pedagogical documentation using digital tools; evaluating digital resources and app(lication)s; blogging and other forms of digital communication. To help them learn to be effective reflective practitioners, ECEs were then closely scaffolded through the reflective cycle using online applications and resources (Dennison, 2009).

Finally, ECEs were engaged in ePortfolio thinking and design. This included higher order thinking skills, and provided the opportunity for ECEs to choose their best work and evidence of learning, and make a convincing argument that they have achieved the learning outcomes (Rowley & Munday, 2014, p. 84). These ePortfolios were created in a private virtual space and could be used beyond the course of study—they become electronic repositories for ECEs to archive, reflect upon, demonstrate, articulate and provide evidence of learning for a variety of viewers. (Munday, 2017).

Throughout the learning process the academic teachers were available through various forms of communication tools: online forums that were created to discuss various issues in teaching with technology as well as to answer questions related to learning content; a Wiki tool where ECEs could propose their investigation topic and engage in peer discussion and support; and scheduled online meetings that were recorded for review and reflection. Using these communication tools meant the academic teachers had an awareness and understanding of the progress of the ECEs and could support their changing feelings and beliefs for using and teaching with technology. This process of scaffolding, rather than instructing the ECEs is fundamental to the constructivist approach where "the teachers' roles shift from dispensing knowledge to helping learners construct more viable conceptions of the world" (Jonassen et al., 2008, p. 242).

7.5 Method

In order to explore more closely the changes in attitudes and beliefs over time, the academic teachers sought, and were granted, ethics approval from the university's Human Research Ethics committee to collect qualitative data in the form of student responses to forum postings, email exchanges, comments made during online presentations and reflective comments made in the second assessment. The academic teachers also received ethics approval to conduct follow up interviews with ECEs who volunteered. Reflective journal entries from each of the academic teachers were also collected.

Participation in the study was conducted via an opt-out method. All ECEs were informed that the academics would be collecting de-identified data throughout the course of the study. Participants were reminded that they could withdraw their data at any stage.

The researchers collected the data over the course of each semester and de-identified it before analysis. In particular, comments that related to a change in attitude, belief or confidence were extracted from transcripts of presentations and conversations during the first assessment task, online discussion forum postings, and reflections regarding their learning in their ePortfolios submitted as assessment 2. For the purposes of this chapter, we have extracted sets of comments from five of the ECEs as examples of attitude change. These five were chosen randomly with three from the face-to-face cohort and two from the online. In the Results section, these five are referred to as ECEs 1 to 5. Five was an adequate number since the evidence given from each ECEs data is consistent. Saunders et al. (2017) talk of this type of saturation as an event or "point at which 'new' does not necessarily add anything to the overall story…" (p. 1900). Although a number of students showed positive attitudes towards this course of study on entry, most of them reported being anxious, unsure, or having negative attitudes.

Also, an invitation was posted annually for participants who would be interested in volunteering for an individual in-depth interview after the conclusion of assessment grading. A student from each year cohort was interviewed—there was no expectation of "additional issues or insights" through this form of qualitative data (Hennink, Kaiser, & Marconi, 2016, p. 592)—rather, it provided an opportunity to collect further explanation and elucidation of the data collected from the other sources. The interviewees were different students to the randomly chosen five and in the Results are referred to as ECEs 6 and 7. The interview questions related to organisational aspects of the course as well as the qualitative study. Questions/topics included:

- Can you talk about the communication strategies being used?
- Online meetings are one aspect of communication, how effective do you find these?
- Comment on the structure, topics and use of the discussion forums.
- Effectiveness of specific tools used: blog, wiki, mobile phone apps, etc.
- Sequencing of the learning materials.
- Usefulness/uptake of the skills learned.

The academic teachers for both cohorts also completed reflective journals that formed part of the data collection. We have included some data in the form of academic teacher journals and reflections in the Results section below to show the awareness of the academic teacher and the scaffolding role they play in the ECEs process of learning.

The academic teachers engaged independently with the data to identify emerging themes (Strauss & Corbin, 1998). They then met and compared their interpretations before deciding on the main 6 themes. The academic teachers then each independently revisited the data drawing out quotes from the participants that represented these themes and resonated with recurring ideas they had observed in their work teaching and working with the ECEs (MacLure, 2013). These quotes have been used in the discussion below in place of contracted 'themes' and are presented as a way to organise the discussion section of this chapter (Maguire & Delahunt, 2017) and highlight the ECEs' voices.

7.6 Results

At the beginning of the 2018 course of study one of the academic teachers used a software application called Zeetings to collect the data in Fig. 7.1 during the first online meeting:

Approximately 20 ECEs were in attendance at this online meeting and anonymously showed that more than half held anxiety about beginning their studies.

7.6.1 ECEs Data

The following qualitative comments (Table 7.1) regarding ECEs feelings, confidence and knowledge of digital technologies were extracted from Assessment presentation transcripts, discussion postings, and ePortfolio reflections, at specific points in the semester to show change in confidence and knowledge.

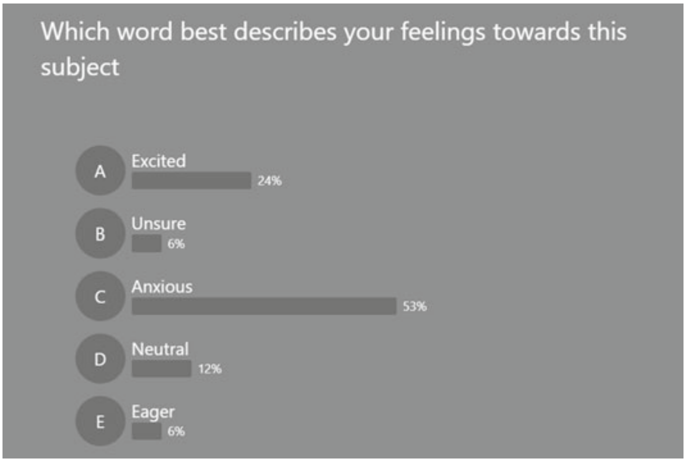

Fig. 7.1 ECEs' feelings towards the subject

7.6.2 In-Depth Interview Data

The following qualitative comments (Table 7.2) were extracted from the transcripts of semi-structured interviews regarding annual course evaluation. The questions are noted above in the Method section. The excerpts chosen expand on the ECEs data included above.

7.6.3 Reflections from Academic Teachers

The qualitative comments in Table 7.3 have been extracted from the reflections of the two academic teachers and respond to the observations of how ECEs are discussing their feelings and witnessing the changes in ECEs attitude and skill. One academic facilitated the learning of the online ECEs in both years, and the other facilitated the learning of the face-to-face ECEs in both years.

7.7 Discussion

The collection of data illumined the effective work the course designers and academic teachers were doing in supporting and scaffolding ECEs in the positive use of digital and online technologies for their personal learning, and in assisting in showing authentic ways of working with young children in ECE classrooms. The representative data was reviewed and discussed and prevalent themes were drawn out. However, the researchers felt that contracting the outcomes into one or two word

Table 7.1 ECEs feelings, confidence and knowledge of digital technologies

	Comment before assessment 1	Comment after assessment 1	Comment before assessment 2	Comment after assessment 2
ECEs 1	For myself personally, I have some preconceived ideas of education technology… the glorified 'teacher-directed workbook' by Tracy Moyer really resonated with me, and was at odds with my thoughts on open-ended exploratory play-based learning, and from my reading I can see that I am not alone in this way of thinking…	…researching this has really opened my eyes to how children can use technology… if I had all the money and all the resources in the world I would like to have the iPads there for the children to play with all the features… like the drawing app… that's where my eyes have been opened up a bit… and it made me think that 'yes' there is quite a bit more children can do with technology… we are still stuck in this structured view, but I'm hoping to go back and talk with them about what I've learned…"	I started this subject with some apprehensions. I am not a tech-savvy person and I did not have a deep understanding of technology. In my work as an early childhood educator, while I agreed that children did need to know how to use technology, I was of the belief that children used enough technology at home to warrant the non-use in early childhood programmes As you will see in this portfolio, as I have engaged with the subject content and my own research, my attitude towards technology use in early childhood spaces has shifted	When I started this subject of study I was not enthusiastic about the topic, but I have really enjoyed the subject. I have enjoyed learning more about this topic and now have a positive attitude towards it. While I may have to contend with the negative attitudes and beliefs towards technology in early childhood from colleagues, present or future, I now have the knowledge, and feel confident to advocate for children's rights to engage with technology
ECEs 2	This subject EMT302 has been interesting and engaging. It outlines ideas as to how technology can impact children learning. This is why I have chosen this subject. Another reason is because, I want to gain knowledge on how to use technology in an ECEC setting allowing children to also have some skills develop by the use of an interactive whiteboard, for example	…imagination can be enhanced through books and short films for children… I [now] get them to come up to the whiteboard and draw the image…	This subject has been interesting, allowing my knowledge and interaction with technology to be developed. EMT302 has enabled my understanding about digital devices to become clearer, expanding the idea of how technology can be used in a variety of ways	During my progress in this subject, I have expanded my knowledge about technology and have learnt interesting facts/information … have allowed me to critically and analytically reflect on my learning and knowledge about technology Each of the two entries highlights a reflective cycle which has guided me to outline my perspective and to critically answer the questions

(continued)

Table 7.1 (continued)

	Comment before assessment 1	Comment after assessment 1	Comment before assessment 2	Comment after assessment 2
ECEs 3	One barrier to teachers integrating technology into their programmes is that they don't recognise the positive impacts technologies can have on children's learning… I have to say that before I started researching this topic, I very much resonated with this statement—I was very hesitant to use digital technologies with children, especially children aged 0-2. My hesitation was connected to my fear that digital technologies would challenge my traditional teaching beliefs and pedagogy. I was also concerned that digital technologies could negatively impact the children's learning…	…it's something that's going to be in their lives forever… I would really like to try Facetime—just as another way for children to feel connected to home while they're at the centre…I think it's a great way for them to connect throughout the day and a way for them to feel secure… I had a child who was drawing a circle with their finger on the screen, and then next time we had pencils and pens I encouraged them to use the same shape with a pencil… yes, exactly, constructing their own knowledge…	This module has really taught me not be so afraid of new technologies as with a bit of patience they can be figures out	My blog discussion talks about the impact of using documentation apps on teachers. The asset shows that I am able to research and discuss both positive and negative implications of online documentation apps

(continued)

Table 7.1 (continued)

	Comment before assessment 1	Comment after assessment 1	Comment before assessment 2	Comment after assessment 2
ECEs 4	To be honest, I am not a technology person… when something goes wrong with my laptop or my phone, I always feel stressed and helpless. However, I also believe that technology is awesome, and as an educator I realise that technology is becoming more and more important…	…I still have some issues with grandparents who can't access the technology… I definitely get more involvement with the parents—before we had to send them an email, but now they only need to click the app… the children also use the iPad to send a message to the parent	Throughout the whole subject content, I have learnt a lot about how to using different technologies effectively in the early childhood settings. Also, after a period of time, my attitude have been changed in regards to using of technologies within my current workplace	As a field we have an opportunity to harness these new technology tools to make a real difference for the young children, parents, and families in our care if we work together to overcome the barriers, and share our best practices with one another. I'm excited about the possibilities and can't wait to see what new tech tools and toys will become available, and the creative ways we will use them in our early childhood programmes
ECEs 5	I chose this topic because I was unsure of the selection process [for apps] Before I started this research, although as an adult, I was comfortable with technology I felt lost	After researching this, I am now very comfortable—you know, looking for things—just googling what the subject might be to find out… Simple is best, I think, after looking at some of these things, for the age of the children… you want ease of use, and in my opinion, you don't want too many	"Trying to stop young children using Technology would be like Neptune trying to hold back the Ocean" (my own thoughts)	When children use technology to research, find facts, solve puzzles or problems, plan/design creations and consider or evaluate their work or the work of their peers, they work with others to mutually reach new knowledge and understanding. Technology allows teachers (if trained, interested, knowledgeable, up-to-date and comfortable with using technology) to provide different experiences for their students. All educators and teachers will require to continually develop their understanding and practices regarding the use of technology to help and mentor effective learning and communication with children and families

Table 7.2 In-depth interview data

2017 ECEs 6	2018 ECEs 7
When I first went into that class I felt like I was going to have a panic attack… but I changed to being an online student, and with you guys being on the Interact2 platform, I was guided through…	I was ignorant to the importance and necessity of using technology in society and initially believed the use of technology with children would be detrimental to their learning and social skills
Technology was not my thing, not really—not interested	I read many articles instructing families to decrease their children's screen time so I struggled contemplating how to explain to families the importance and benefits of incorporating technology in their children's programme when I did not believe it myself
Every single aspect of the assessment tasks were new to me—I'd never made a presentation, I'd never even made my own slides	I never ventured using technology out of fear of using it, fear of being judged by the children's families and other educators and fear of corrupting the software
EMT302, I found [to be] quite a creative outlet—once I realized that I was capable… I was capable of creating a flipgrid, and I was capable of creating a presentation using the computer—I was previously unaware of the potential of what it could do…	I am learning new ideas and interests alongside with the children. It has also empowered me to role model to the children how to problem solve and discover information on a subject of interest using various forms of technology
It got me thinking about things that we take for granted… but I'd never critically thought about how that evolved… and now it makes me look at things differently and appreciate the effort and time it takes to build such things…	This unit has given me the push to leave my comfort zone and research the benefits of technology use for children and put it into practice. It has allowed me to explore and trial new things without the dreaded fear and trepidation that usually accompanies me when I use technology. It has given me the confidence to implement technology into the children's programme and to explain to educators and families the importance of teaching children about the technology that surrounds them daily. It has enabled me to understand the pros and cons of technology use with children and use the cons as a guide to ensure that the technology I am introducing is purposeful and engaging
I was excited about what I was learning, and I'm quite a creative person… through my own doing, I did way too much… I designed all those things, and I was inspired by what I saw as examples	I realised I had to give children positive activities involving technology that are purposeful and engaging

Table 7.3 Reflections from academic teachers

Face-to-face academic teacher	Online academic teacher
Typically within their day to day lives student usage of technology involves the use of mobile phones and social media platforms such as Facebook. Within their professional lives, the use of technology is typically dominated by the creation of digital documentation, primarily through commercial-based online services used by their employers. A lack of confidence in the usage of digital mediums is common within the cohort whether it be usage for personal or professional reasons	They [the ECEs] are all working, in my experience—there might be one or two. I haven't got any this semester, and maybe one last semester [who are not working in the field]… The presentations are fantastic, and they are working on them now… they are deep questions, and good thinking… they freak out a bit over the technology, and sometimes I need to 'hold their hand', but they all get there… The topics now cover issues—they talk about technologies within their discussions…
It is during this class typically that a mind shift for the students occurs, recognising the familiarity of technology in their daily lives, accepting that this is not something 'new' and therefore feeling more comfortable with the concept. As they now begin considering *how* technology can be used and *why* their minds begin to open to the possibilities and the opportunities technology affords their pedagogy	We're not going to give them a list of cool tools to use, its more constructivist… the ideas the subject develops are actually much broader and can be applied in many situations…
During our classes in these weeks students are challenged to engage in personal reflection to consider this cognitive conflict and consider what it is that is influencing their beliefs—is it experience? Knowledge? Media reports?	Reflective practice is still very strong—that's a beautiful part of the subject The flipgrids are deep and thoughtful—I get them to reflect on what is technology I haven't had any issues, and they're all blogging It is a PebblePad blog and then they choose which blog entries to add into their Portfolios
As knowledge and confidence increases students become more open to possibilities within their work, considering the use of technology beyond just creating documentation for families	It's definitely a rich environment, and there's lots on the tablets and the mobile devices
What emerges for most students is an understanding of the need to be a *controller* of technology rather than merely a *consumer*. Students begin to understand the need for critiquing technology and its usage the same as they do any other educational resource	

themes diminished the richness of the story being told (Braun, Clarke, Hayfield & Terry, 2019). Therefore, quotations have been extracted from the qualitative data as headings or themes in order to organise the discussion (Phillips, 2012). There are six headings in inverted commas to show they are direct quotes from the data.

1. "**I have some preconceived ideas of education technology**"

Many of the ECEs were able to self-identify that they arrived at the beginning of the course of study with fixed ideas about ways children learn and the place of technology in the ECE classroom. Hatzigianni & Kalaitzidis (2018) remind us that "a teacher's philosophy can directly affect how technology is integrated". (p. 885). Rather than telling the ECEs they needed to change their approach, the academic teachers supported the ECEs in their independent research, which tended to bring about a more powerful change of mind. ECEs 1 believed herself to not be "tech-savvy", however, by the end of the course was willing to advocate for the rights of young children to learn with technology.

2. "**That's where my eyes have been opened up a bit**"

Through the course of study the ECEs were introduced to many types of digital hardware and software. Of course, there remains an investment issue for ECE centres, as funds being used for technology tools and resources are expensive. One ECEs reported that the only technology device available where she worked was an old iPad, on which she felt she was limited in regard to engaging the children in authentic learning. Both ECEs 1 and 2 show evidence of realizing the possible value of digital tools being devoted to more creative knowledge building, and resolved to share their knowledge and enthusiasm with colleagues and supervisors.

3. "**Have allowed me to critically and analytically reflect on my learning and knowledge**"

"Through critical reflection, educators come to new understandings" (Anderson, 2014, p. 81). The reflective cycle was presented to the ECEs in a number of ways—online forums, blogs, ePortfolios—in order to emphasise the value of re-thinking actions and decisions. ECEs 4 talks about changing her opinion about how technology tools can be used in the ECE environment and ECEs 2 points directly to reflective practice regarding her ability to critically analyse information she collected for her ePortfolio. All of the ECEs exerpts show evidence of constructing their own knowledge and the change in their confidence will directly be related to a change in their practice with young children.

4. "**After researching this, I am now very comfortable**"

"Through the integration of technology, students have opportunities to learn how to use technology tools, while at the same time engage in authentic learning experiences" (Cydis, 2015, p. 70). The course designers and academic teachers engage the ECEs in authentic learning through having them investigate a real-world topic in technology and ECE; critically analyse existing apps; engage in ePortfolio thinking and processes; and experience the reflective cycle through blogging. ECEs 5, 6 and 7 explicitly refer to their research activities in the subject as authentic learning which gave them the opportunity to explore and trial technologies.

5. "**To be honest, I am not a technology person…**"

"Although many people assume that preservice teachers are digital natives and, as such, confident with technology use, given the diverse cohort of preservice teachers including mature aged, international, and rural and remote learners, such an assumption is naive" (Highfield & Papic, 2015, p. 424). During the presentations of the first assessment task, the number of ECEs self-identifying as non-technology people was very high. As discussed in the literature review, there is a perception that young teachers, and teachers of young children, will have high confidence in using technologies (Koch, Heo, & Kush, 2012). But it is very evident in our data collection that a large proportion identify themselves as non-users, which contributes to their apprehension at the commencement of the course of study. Both ECEs 6 and 7 explain this apprehension which gradually changes to confidence and then the intention to use technologies in their work.

6. "**All educators and teachers will require to continually develop their understanding and practices regarding the use of technology to help and mentor effective learning and communication**"

Whilst there is no explicit process for mentoring articulated in the course of study, there is strong evidence of peer mentoring within the student cohort, particularly in the process of defining the topic of investigation that is the first assessment task. The academic teachers strongly mentor the students in all aspects of the learning process, which is evident in the journal excerpts from both academic teachers. However, through the wiki tool that is used for discussion between the academic teacher and the ECEs, other ECEs offer advice and help. Throughout the presentation period, peer support is strongly evident through peer attendance at presentations, along with questions and comments provided to the presenter. ECEs also talk of mentoring their fellow educators back in the classroom, and propose discussing with supervisors how their learning could be brought to productive learning with young children. ECEs 5 and 7 clearly intend to share their learning and support their colleagues.

7.7.1 Limitations of the Study

The researchers acknowledge the small nature of the research study and the restrictions placed upon their data collection. Data was collected through regular student activities and interviews undertaken after the conclusion of assessments and grading. While the researchers acknowledge the possibility that the student-teacher relationship may have impacted some of the responses, the academic teachers reminded students that they could withdraw their data and that all data would be de-identified prior to analysis. A deeper research study could be undertaken with independent researchers who are not part of the course design and teaching team. The data provided in this chapter is only a portion of the entire collection from the cohorts over the two year period; however, the researchers believe the responses capture the change in attitude and belief over time for many students.

7.8 Conclusion

The meaningful integration of digital technologies in ECE is of utmost importance. It opens possibilities, extends opportunities, connects the formal learning environments to students' life-worlds and is an integral component of a meaningful STEM programme. The quality of the STEM experiences we offer young children is limited by educators' confidence and expertise in designing learning experiences in all of the individual elements of STEM. Despite widespread understanding of the importance of this, fear remains that ECE teachers are not always confident to integrate digital technologies meaningfully. The data collected in this small study illustrates ways that we can work with ECEs to build confidence and evoke changes in attitudes in regards to the role of digital technologies in ECE. The participants showcased here demonstrated a definite change from the beginning of the course of study where they readily admitted they feared technology or believed that technology does not have a place in the ECE classroom, to confidence in not only using technology tools, but articulating the great value these tools hold for their own and young children's learning. It seems very suitable to provide a final quote from ECEs 7, as a succinct conclusion:

> This unit has given me the push to leave my comfort zone and research the benefits of technology use for children and put it into practice. It has allowed me to explore and trial new things without the dreaded fear and trepidation that usually accompanies me when I use technology. It has given me the confidence to implement technology into the children's programme and to explain to educators and families the importance of teaching children about the technology that surrounds them daily. It has enabled me to understand the pros and cons of technology use with children and use the cons as a guide to ensure that the technology I am introducing is purposeful and engaging. By shielding the children from the use of technology can instill a fear of technology and alienate them from future educational studies and how they are perceived socially (ECEs 7, 2018).

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Chapter 8
Digital Technologies and Numeracy—Synergy or Discord?

Kevin Larkin and Jodie Miller

Abstract Engaging young learners in STEM practices such as robotics and coding gives students the opportunity to use new and emerging technologies to solve problems while extending their own knowledge and understanding of mathematics. In Australia, a digital technologies curriculum was introduced in 2014 to assist with making connections between Technology and areas such as mathematics. Drawing on examples from Australia, British Columbia, the United Kingdom and New Zealand, this chapter examines how the introduction of a new curriculum intersects with existing curricula. As an example of an authentic activity that successfully combines elements of both curricula to support STEM learning, findings of a research project that has been conducted with Year 2 students (n = 153) from two Australian primary schools are presented. It appears as young students engage in robotics and coding (Technology) to learn mathematics concepts, they demonstrate learning that moves beyond their curriculum year level, creating a possible conflict between the digital technologies and mathematics curricula with their tightly prescribed sequence of content.

8.1 Introduction

The past decade has been characterised at all educational levels, from Early Childhood to University, by an international urgency to improve Science, Technology, Engineering and Mathematics (STEM) education in preparation for an increasingly scientific and technological society (Office of Chief Scientist, 2014). This push to improve STEM is often based on claims regarding the rapid decline in school students' engagement in STEM disciplines, e.g. Advanced Mathematics, Chemistry or Physics (Australian Academy of Science [AAS], 2016). Disengagement in STEM

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appears to begin at an early age (Larkin & Jorgensen, 2016; Moomaw & Davis, 2010), with many students from the upper primary years onwards performing poorly in, and disengaging from, mathematics (AAS, 2016), identified as the core subject in STEM (Finkel, 2017). To address a component of the broader STEM issue, a new Digital Technologies (DT) curriculum was introduced in Australia in 2014, to encourage, amongst other outcomes, the development of computational thinking in children across the formal years of schooling (F-10). Whilst, the convergence of policy and curriculum directions is heartening; it is also highly problematic as there is a limited evidence base to inform the implementation of STEM more generally in classrooms (English, 2016) and even less in relation to the implementation of DT as a discrete curriculum. Of particular concern is how the introduction of a new curriculum intersects with existing curricula. Does the new DT curriculum encourage opportunities for synergy with existing curricula, particularly mathematics, or is it yet another example of how new curricula are developed in isolation and when implemented, bring discord? Prior to examining this issue specifically as it relates to the Australian context, and before proposing an authentic classroom experience that combines elements of both curricula, it is opportune to consider whether, and then if necessary how, the issue of integrating digital technologies into existing curricula is dealt with internationally.

8.2 The International Context

In terms of an international perspective regarding DT curricula, we follow the methodology of Watson (2017) who used the curriculum of three English-speaking countries—Australia, New Zealand and the USA to investigate the teaching of Statistics. Thus, whilst acknowledging that curriculum documents in other countries may differ, for the purposes of this chapter we have focused on the curriculums, with explicit mention of digital technologies, in educational jurisdictions in four countries: Australia, British Columbia (Canada), the United Kingdom and New Zealand.

Least developed in terms of jurisdictions with DT explicit in the curriculum is British Columbia (Canada) where DT are included within a broader Applied Design, Skills and Technologies (ADST) curriculum envisaged as “an experiential, hands-on program of learning through design” (British Columbia Government, 2016, p. 1). The ADST is organised around three curricula competencies—Applied Design, Applied Skills and Applied Technologies—with technologies defined as “tools that extend human capabilities” (p. 1). While the ADST provides a breakdown of activities to be completed at different learning stages (K-3; 4–5; 6–7) these activities only minimally include DT and only then as a subset of the total range of technologies (both digital and nondigital) that children will encounter. Similarly to other educational jurisdictions such as California (USA), “the ADST Curriculum does not specify any content learning standards for Kindergarten through Grade 5 as “the intent is for teachers to use the Curricular Competencies from ADST K-5 with grade-level content from other areas of learning” (British Columbia Government, 2016, p. 4).

The United Kingdom is somewhat more explicit in recognising the role of DT in helping students understand their world (Department for Education, 2013). Their National Curriculum identifies four aims for computing, two that mirror goals of the Australian DT curriculum (algorithmic thinking and writing computer programs) and two which relate more to the Australian ICT general capability (evaluating ICT and being ethically responsible users). A limited content base is provided for teachers at various Key Stages, e.g. at Key Stage One, broadly equivalent to F-2 in Australia, six dot points on content to be taught are prescribed (Department for Education, 2013), including again what would be considered as both DT curriculum and ICT general capability content in an Australian context. However, these dot points contain minimal information are therefore unlikely to assist teachers when planning to integrate DT and numeracy content.

With the recent release of the New Zealand DT curriculum (Ministry of Education, 2017), this jurisdiction most closely resembles the Australian context. The main modification to the previously existing Technology Learning Area is the addition of computational thinking for digital technologies. According to the new curriculum, "computational thinking enables students to express problems and formulate solutions in a way that a computer can be used to solve them. They also develop knowledge and skills in using different digital technologies to create digital content for the web, interactive digital platforms, and print" (Ministry of Education, 2017, p. 11). As was the case with British Columbia, no specific content is provided for teachers; however, very concise progress outcomes for key stages are mandated and within these outcomes, specific content can be found. For instance, at Progress Outcome Two (roughly Year 3 in Australia), students are required to write computer programs (using algorithmic thinking) such that computers can clearly follow them and then use these algorithms in an age-appropriate programming environment—e.g. *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group, & Playful Invention Company. [*ScratchJr*]), undated). Exemplars of student outcomes at various stages are also provided—(e.g. in Year 3 students programme a bee to visit various flowers to gather pollen using *ScratchJr*). So whilst no explicit content is provided, teachers can gain a sense of what they are to teach and can therefore, at least in principle if not in practice, begin to think about how this might be incorporated in existing numeracy activities. The brief account of what is occurring around the world indicates that, to varying degrees of specificity, DT is on the educational agenda in the three English-speaking jurisdictions discussed.

8.3 The Australian Context

Having briefly scanned the international educational context we now turn to the Australian context. In so doing, as was the case with Watson and Neal (2012) who examined only one curriculum sub-strand in one country, we make use of a number of specific instances of mismatches and missed opportunities in the two Australian Curriculums to reinforce the more generalised observation that national curriculum documents from many countries have failed to capitalise on opportunities for synergy between digital technologies and numeracy education.

In 2014, The Australian Curriculum and Reporting Authority (ACARA) released the inaugural Technologies curriculum: subdivided into Design Technologies and Digital Technologies (previous to this Australia had a Technology Curriculum that incorporated both but did not specify digital content). Given that this article concerns connections among coding, robotics, numeracy and mathematics, we limit further discussion to the DT curriculum as it is presented in the Foundation to Year 6 (approximately 5–11 year olds) levels. The DT curriculum in primary school is divided into three bands (F-2; 3–4 and 5–6) and these bands are further subdivided into content descriptors under the two subheadings of *Knowledge and Understanding* and *Processes and Production Skills*. Readers familiar with the Australian mathematics curriculum will see some connections between the development of data concepts in both the DT and mathematics curricula. We will see later that at times this can be problematic. Within each subheading there are content descriptors and accompanying elaborations that provide further information related to the specific content descriptor. For example, in Year 4, under the *Knowledge and Understanding* subheading the students—*Examine how whole numbers are used to represent all data in digital systems* with one of the elaborations for this content descriptor being *explaining that binary represents the numbers using 1s and 0s and these represent the on and off electrical states, respectively, in hardware and robotics.*

8.4 Numeracy and the Digital Technologies Curriculum

An examination of the DT curriculum raises a number of issues in relation to the overarching goal of all curriculum areas to develop numeracy and numerate citizens (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2016a). These issues fall broadly under the categories of: (1) the mismatch between numeracy understandings developed in the DT curriculum and how numeracy is developed in the mathematics curriculum; (2) superficial or inauthentic links to numeracy and (3) missed opportunities to engage with authentic numeracy opportunities.

8.4.1 Mismatches in Mathematical Understanding Promoted by the Two Curricula

Many of the mismatches between the two curricula occur in the F-2 section of the DT curriculum. As the mathematics curriculum is designed at a year level designation—i.e. Foundation is separate from Year 1, which is separate from Year 2; and the DT curriculum is organised across the three years, it is not readily apparent when in the

DT curriculum the various activities are to be completed. This adds to the potential confusion for teachers when implementing both curricula.

Within both curricula, content descriptors are coded. By way of example, *ACTDIK002* is a shortcut for "Australian Curriculum Technology Digital Knowledge and Understanding Content Descriptor Two". This particular content descriptor indicates that students in F-2 are to—*Recognise and explore patterns in data and represent data as pictures, symbols and diagrams*. It is not made clear what representing data using "diagrams" involves; however, this competency is likely to be beyond most early years students as the corresponding mathematics content descriptor only requires them to initially investigate simple yes/no questions (Year 1) and then represent simple categorical data using picture graphs (Year 1) or tally marks (Year 2). Within the overarching content descriptor, one of the elaborations requires students to discuss that the symbol 12 *may* represent different data to the symbol 21. Given that students at this age are beginning to develop conceptual understanding of place value, this elaboration is likely to cause confusion if the two representations are used interchangeably.

A second DT elaboration at this level requires students to change pixel density to represent changes in data. Again, given that understanding pixels requires knowledge of scale and proportion, and may even require knowledge of decimals, this will very likely be beyond anything other than a superficial understanding by young students. Furthermore, the students are also required to link the resolution of the photograph to its file size, a task requiring knowledge of scale, which is a concept only developed in the final years of the primary school mathematics curriculum.

In the DT curriculum, students in F-2 are required to—*Collect, explore and sort data, and use digital systems to present the data creatively*. This content descriptor is problematic, as the elaboration requires students to locate and purposefully use visual or text data found from digital sources. This is in direct contradiction to the explicit emphasis in the mathematics curriculum on the use of primary (i.e. data collected by the students from their experience) rather than relying on secondary data (i.e. data from web sites) in the early and middle years of primary school. In addition, in relation to pictorial representation, in the F-2 DT curriculum elaboration, students are to use column graphs to represent different types of items; however, this form of representation is not introduced until at least Year 3 in the mathematics curriculum.

In a second example from F-2, students in the DT Curriculum are required to—*Follow, describe and represent a sequence of steps and decisions (algorithms) needed to solve simple problems*. Most of this descriptor and accompanying elaborations match with the respective mathematics content, except for the observation that students are to plan their sequences and steps using metric units—which are not introduced until Year 3 in the mathematics curriculum. The delay in using metric units in the mathematics curriculum is deliberate and based on the research literature regarding measurement (Clements & Sarama, 2014) and is an important step in the development of spatial reasoning and measurement.

Whilst overall reasonably accurate in terms of mathematical terminology, there are a few examples in the DT curriculum where careless use of mathematics terms may cause confusion. One example, in Year 3 and 4, is the content elaboration that includes, in part—*three circles, drawn as lines*. Given that lines are one dimensional and circles are two dimensional and constructed from curves this is likely to be problematic. A second example occurs when children are asked to examine datasets regarding modes of travel—whilst mode can refer to type; its use in mathematics is normally reserved to refer to a measure of average.

It could, of course, be argued that students are capable of successfully completing many of the mismatched activities noted above; however, given that mathematics education experts designed the mathematics curriculum, it is highly likely that the mismatches generated from the DT curriculum side of the equation might be problematic for the numeracy development of young children. Given that both the numeracy general capability and the mathematics curriculum were in place well before the release of the DT curriculum, it is disappointing that these mismatches have occurred, as they are likely to cause some confusion for early years teachers responsible for delivering both curricula.

In addition, if we are to take ACARA at its word, the various individual curriculums are designed to work synergistically, especially when it relates to the development of the general capabilities, in this instance numeracy, which spans the entire range of curricula. It is thus disappointing that there are mismatches between the mathematics and DT curriculum in terms of developing numeracy. Furthermore, we shall shortly see that the DT curriculum, on some occasions, either treats numeracy in a superficial manner, or fails to take the opportunities provided to develop numeracy when this could easily have occurred.

8.4.2 Superficiality

As hinted above, in addition to mismatches between the DT and mathematics curricula in terms of content and language, of great concern is the generally superficial way that connections are made with the numeracy sub-elements of *Interpreting statistical information* and, to a lesser degree, *Using spatial reasoning*. Here we will focus only on the superficiality of the links from the DT curriculum to support the development of *Interpreting statistical information*. This numeracy element requires that students "gain familiarity with how statistical information is represented and to use data gathered in authentic contexts to solve problems" (ACARA, 2016a).

Superficiality in relation to statistics is prevalent across all three primary bands of the DT curriculum. In Year F-2 three of the elaborations accompanying the content descriptor—*Follow, describe and represent a sequence of steps and decisions (algorithms) needed to solve simple problems*—are linked to the *Interpreting statistical information* numeracy component and thus are meant to serve as exemplars of how this component can be developed. It is not immediately apparent to the authors how, for example—*scanning personal photographs* or *presenting a set of instructions or events in a slide show* or *instructions for recording a TV show or how their lunch* *order is delivered*—is in anyway a statistical understanding. Whilst there are certainly valuable learnings in terms of programming, it is inaccurate to imply that these develop students' skills in interpreting statistical information.

Both the previous content descriptors are related to process; however, the superficial links to statistics are also evident in one of the knowledge and understanding content descriptors in Years 3–4—*Identify and explore a range of digital systems with peripheral devices for different purposes and transmit different types of data.* However, there is no evidence of statistics knowledge required in any of the three accompanying elaborations for this descriptor. In addition, in the descriptor—*data can be represented in different ways* with one elaboration indicating that *Identifying statistical information* is used when *recognising…waves for sound.* This is a complex scientific understanding, of little immediate relevance mathematically to students in Years 3 or 4, and unlikely to help them to become more numerate.

8.4.3 Missed Opportunities

In direct contrast to the superficiality of some links to numeracy elements presented in the DT curriculum, the reverse is also the case with many authentic opportunities for connection with numeracy components overlooked. In Year 3–4, *students are required* to *transmit different types of data* and the elaboration focuses on the device type (Interactive White Board [IWB], mobile); however, no links are made to the numeracy general capability. This is an ideal opportunity for students to transmit authentic data that they have collected in meaningful statistical activities, for an authentic purpose, e.g. to communicate to parents, peers or other schools. In addition, while we agree with the content descriptor—*students should be developing an understanding that data can be represented in a variety of digital forms*, it is a clear oversight not to link this elaboration back to numeracy learning outcomes given that numbers are forms of data. Problem-solving is a core component of the content descriptor—*Define simple problems, and describe and follow a sequence of steps and decisions (algorithms) needed to solve them*—and yet, despite problem-solving being one of the four overarching proficiencies of the Australian Curriculum: Mathematics—there is no link to either the numeracy general capability or the Problem-Solving Proficiency in the first elaboration where methods for solving problems are discussed. This would have been an ideal opportunity to connect with various problem-solving strategies promoted in the mathematics curriculum and vital for numeracy.

Our premises thus far have been that

1. In most international curricula, the role of DT has yet to be fully articulated and thus creating synergies between DT and mathematics is very difficult for teachers.

2. In Australia, and to a lesser extent the UK and New Zealand, the DT curriculum is more clearly articulated; however, there are numerous examples of content mismatches, lack of authenticity in connections that are made, and missed opportunities to engage students in learning incorporating both curricula.

Our conclusion is therefore that it is necessary to assist teachers in developing opportunities for authentic synergies between the two curricula, whilst still remaining true to the intent of each of the individual curricula. In the remainder of this article, we outline how *ScratchJr*, a coding program for young children, offers some potential in bridging between the DT and the mathematics curricula to develop student's programming and algorithmic skills, and hence their overall numeracy, as required in both. Before looking at how this might occur, it is necessary to digress briefly to investigate the role of programming in schools in general, and the usefulness of *ScratchJr* in particular as a tool to support programming skills.

8.5 *ScratchJr* as a Programming Language for Young Children

ScratchJr (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) is a visual programming (henceforth coding) language developed by the Lifelong Kindergarten group at MIT Media Labs to promote creative thinking, reasoning and innovation (Resnick et al., 2009). The rich digital environment of *ScratchJr* utilises building block command structures to manipulate graphics, audio and video functions (Calder, 2012). The building block commands are forms of simplified syntax; hence students are not required to type the code themselves, rather they drag and drop the interlocking blocks of symbolic code together to create chains of code. There are ten categories of building block command structures, and each of these is represented by a specific colour. Examples of these categories include: motion blocks (blue); logic/control blocks (gold); and, data blocks (orange) (Francis, Khan, & Davis, 2016). Each coding block also incorporates text and symbolic commands to assist the user to select the appropriate code for the action that they would like to undertake. Similar to the *LOGO* turtle (Papert, 1980), the *ScratchJr* interface enables a cat to move on a two-dimensional screen. Figure 8.1 presents the *ScratchJr* interface with an example of one chain of code for drawing a hexagon.

8.6 Studies Focusing on Programming

A body of research indicates that coding provides an opportunity for developing students' cognition and mathematical knowledge (Papert, 1980). Noss and Hoyles (1996) state that "writing a computer program provides a broad canvas on which

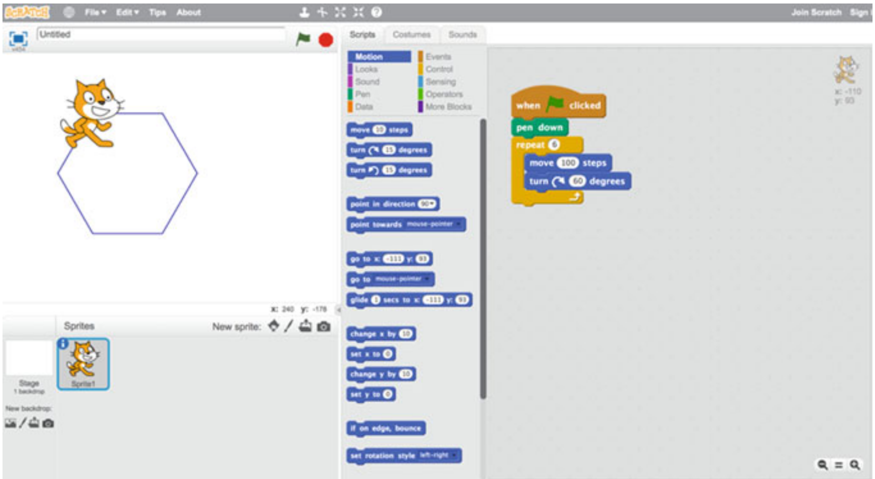


Fig. 8.1 *ScratchJr* interface

the learner can sketch half-understood ideas, and assemble on the screen a semi-concrete image of the mathematical structures he or she is building intellectually" (p. 55). Research into student learning through coding and programmable robots, including the use of *LOGO* (Clements, Battista, & Sarama, 2001) and *BeeBots* (Highfield, 2010), have indicated that programmable robots support students in problem-solving, reasoning and spatial concepts (Savard & Highfield, 2015), key components in the repertoire of a numerate person. In addition, findings from quantitative studies have revealed that there is a correlation between computer coding using *Scratch* and mathematics outcomes for Year 5 students (Lewis & Shah, 2012). However, with the exception of research conducted using *LOGO*, research into coding is in its infancy, and where using *Scratch* as a programming language has been investigated at all, these investigations were in middle school contexts. Finally, Benton, Hoyles, Kalas and Noss (2017) stress that much of the past research into the impact of coding on students' numeracy development is inconclusive due to the diversity of research paradigms adopted in these studies.

Although there have been pockets of enthusiasm regarding the teaching of coding (e.g. *LOGO* and *BASIC*) in the last three decades; several factors have limited its wider adoption in school classrooms: students found mastering the programme syntax difficult; programing often had little connection to young people's interests (e.g. generating a sequence of primes); and there was limited expertise available to support teachers and students using either programming language (Resnick et al., 2009). Despite the fact that the teaching of coding is now mandated in the Australian Curriculum: Digital Technologies, the case can still be made that support for implementation remains problematic with a pessimistic view proposing that many generalist primary school teachers are underprepared to teach coding and therefore will likely have difficulty in establishing links between coding and numeracy (Benton et al., 2017). In addition to these problems is the observation that the underlying numeracy elements, potentially developed by students when they engage in coding, can remain hidden from teachers who, due to unfamiliarity with coding or coding programs, often over-focus on the use of the tool (either a visual coding program such as *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) or robots such as *BeeBots*) rather than the numeracy requirements within the tasks (Savard & Highfield, 2015).

8.7 Linking Programming and Numeracy in the Australian Curriculum

As outlined previously, coding is now an explicit content requirement, embedded in various degrees of complexity across the entire scope of the F-10 DT curriculum. Students are required to use "computational thinking and information systems, to define, design and implement digital solutions" (ACARA, 2016a) and by the end of Year 2, for example, students will "develop their design skills by conceptualising algorithms as a sequence of steps for carrying out instructions, such as identifying steps in a process or controlling robotic devices" (ACARA, 2016a). In determining the ways in which the DT curriculum relates to the development of the numeracy general capability, an important consideration is its alignment with the preexisting mathematics curriculum. Given that the remainder of this chapter concerns the use of *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) in a teaching experiment with Year 2 students, we will limit our focus to the relevant Year 2 mathematics and DT content descriptors, as displayed in Table 8.1.

The limited scope of studies focusing on the classroom and curriculum implementation of coding (Lye & Koh, 2014) supports our earlier argument of the need to examine the relationship between DT and mathematics curricula in supporting the development of the general capability of numeracy. As teachers use curricula to manage their planning, teaching and evaluating of student learning; making the mathematics in coding explicit for teachers is essential as this will encourage them to develop programs of work that encourage synergy between the DT and mathematics curricula rather than the discord suggested by our initial review. We now outline a component of a broader research project involving the teaching of coding and robotics to demonstrate how teachers can authentically integrate elements of the two curricula to achieve the curriculum intent of both without compromising the integrity of either.

Table 8.1 Mathematics and digital technologies content descriptors and elaborations

Subject	Content descriptors	Elaborations
Mathematics year 2: geometry	Describe and draw two-dimensional shapes, with and without digital technologies	Identify key features of squares, rectangles, triangles, kites, rhombuses and circles, such as straight lines or curved lines, and counting the edges and corners
Digital technologies foundation—year 2: process & skill production	Follow, describe and represent a sequence of steps and decisions (algorithms) needed to solve simple problems	Experimenting with very simple, step-by-step procedures to explore programmable devices, for example providing instructions to physical or virtual objects or robotic devices to move in an intended manner, such as following a path around the classroom

8.8 The Teaching Experiment

A six-week coding and robotics teaching experiment was conducted with Year 2 students to explore how students developed mathematical reasoning (Steffe & Thompson, 2000) and numeracy as they participated in coding and robotics lessons. One of the researchers (author 2), in consultation with the class teacher, assumed the role of teacher in these experiments at both school sites. Of course, any teaching experiment is a point in time experience for the students and we, as previous primary school teachers ourselves, acknowledge that the following account does not critically analyse what impact the design of the lesson, or the teacher's way of teaching, had when discussing the students' test results. However, we are confident that classroom teachers could very effectively teach the lessons presented here.

The teaching experiment comprised of: pre-testing; 6 × 45 min lessons of either coding or robotics lessons (one lesson per week for six weeks with two groups of 10 students at each school site); and post-testing. Six classes of Year 2 students (age 7–8 years old) from two schools participated in the study. In total, there were 153 Year 2 students: 74 students from School A, and 79 students from School B. Both schools were matched for socio-demographic characteristics and are positioned just above the median for socio-educational advantage (School A = 1,056; School B = 1,037; ICSEA median value 1,000—*My School* website data, ACARA, 2019). The complete teaching experiment consisted of six lessons, three with a coding focus using *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) and three with a robotics focus using *LEGO Mindstorm* robots. Each lesson focused on teaching a mathematical concept using coding or robotics (e.g. drawing a shape using *SratchJr*, or programming a robot to follow a particular path). Two video cameras were used to collect data during each lesson with one camera focussed on the researcher and one on a group of students. These video recordings were used for in depth analysis by the authors.

In order to identify their prior patterning and coding knowledge, each participant completed a pen and paper pre-test focussing on patterning (10 items) and *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) coding contexts (10 items). Patterning test items, validated in earlier research (Warren & Cooper, 2008; Miller, 2015), were modified to assess coding skills. Data from the pre-tests were analysed to determine a smaller, experimental group of students ($n = 40$) to participate in the coding and robotics lessons. Students were selected on their prior knowledge of patterning and coding (low-mid-high test scores). There were four subgroups of students identified: low patterning/low coding; low patterning/mid coding; mid patterning/low coding; and mid patterning/mid coding. Although a possible outcome, no students were classified as high in either pattering or coding. Students who were not selected for the study ($n = 113$) stayed with their classroom teacher and participated in normal class lessons as planned by their teacher for that time. These teachers ($n = 6$) did not teach robotics or coding in their classrooms during the experiment. At the conclusion of the six weeks, post-testing (patterning and coding items) was conducted with all students ($n = 153$).

A two-stage research approach, using iterative refinement cycles for videotape analyses of changes in students' thinking (see Miller, 2015), was adopted to analyse the data from the teaching experiments (Lesh & Lehrer, 2000). First, the lesson video-footage was transcribed to capture students' verbal responses. These transcriptions were then analysed to consider emerging algorithmic thinking, computational thinking and numeracy development during the lesson sequence. Second, the student responses to the coding and robotics lessons were analysed to align the curriculum descriptors from both curricula. As the purpose of this article is to provide an example of how skills required in the two curricula can be developed simultaneously, we only present findings from the first lesson in the teaching experiment where students were required to draw a square using *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) (See Fig. 8.2). Further outcomes of the entire teaching experiment will be reported in full elsewhere.

8.9 Findings and Discussion

The findings are presented in two parts. Firstly, the emerging connections between mathematical thinking and coding evident in the students' response to the "Draw a square" task are discussed. Secondly, how this thinking is aligned to/misaligned with the content descriptors of each curriculum is reviewed. Each of the 40 students provided a response to the task. After analysis of the student responses, it was evident that there were five common types of responses (see Table 8.2) to the "Draw a square" task.

Task	Mathematical concepts	Scratch coding concepts
Scratch Cat's favourite shape is a square. Can you help Scratch Cat draw a square? 	Discussing properties of a square Testing and measuring lengths. How far is one step in Scratch? Testing and measuring Angles/turns Identifying any repeating patterns	Exploring the coding blocks and symbols used in scratch Measuring in pixels Building a code Running a code Editing a code if there are errors Using the repeat/loop function

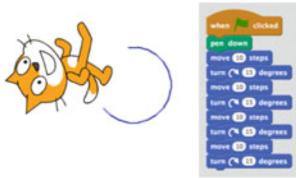
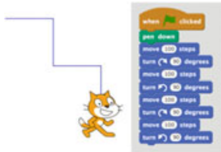
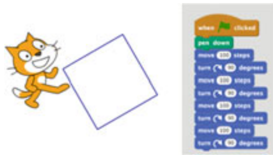
Fig. 8.2 Drawing a square using *ScratchJr* with links to mathematics and coding concepts (Miller & Larkin, 2017)

When considering the student responses, in terms of the content descriptor requirements of the Year 2 mathematics and DT curricula (see Table 8.1), it is evident that some students were working at a higher level than required by either curriculum. There were three key insights from the data that demonstrated high levels of mathematical reasoning or programming: namely, working with 90° turns; orientation and perspective taking; and deducing a repeating pattern to provide a generalised code for making a square. When drawing a two-dimensional shape, using a digital tool such as *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated), an opportunity exists for students to engage with higher levels of mathematical reasoning or coding than required by their respective curricula. This may occur for three reasons: first, as a consequence of the visual programing language (icons) and representations; second, the perspective taking that performing the task requires; and, third the ability to easily create a coding chain that represents the algebraic structure of the physical shape they have drawn.

First, when using *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) to draw a square, it appears the language and representations depicted in the coding blocks require high levels of mathematical reasoning and knowledge, beyond the curricula requirements for these young students. For example, *ScratchJr* uses measures of degrees for turns, rather than mathematical language such as ¼ turn, and thus the software is, therefore, more sophisticated than programmable robotics toys, such as the commonly used (e.g. *BeeBots)* that merely use a left or right arrow to perform a 90° turn. By contrast, when using *ScratchJr*, students are required to program the *ScratchJr* cat to perform an accurate 90° turn using a variety of programmable blocks.

This is an example of where the coding structures available in the software can assist students to extend their mathematical reasoning beyond the strict requirements of the mathematics curriculum. For example, according to the Year 2 Mathematics curriculum, students are only required to identify turns using the language of "quarter and half turns" and it is not until Year 5 that students are required to understand angles

Table 8.2 Student response and explanation, frequency of student responses, and student exemplars (Modified from Miller & Larkin, 2017)

Response and explanation	Frequency	Example
I can't draw a square but I can draw a hexagon Student attempted to draw a square but used a number of 15° turns. Whilst not a hexagon, the majority of students said they were creating a hexagon. They clicked on the code four times to make this shape	8	
I can draw stairs: Why is the cat not turning the right way? Students did not construct a square as they alternated the turns right and left	4	
Is this still a square? Students correctly programmed the cat to draw a square, however, due to its nonstandard orientation, were unsure whether a square had been drawn	3	
I made a square Students were able to program the *Scratch* cat to draw a square parallel to the bottom of the screen	20	
I can see a pattern: move, turn, move… Students identified that they can see a repeating pattern and used the repeat coding block to program the *Scratch* cat to draw a square	5	

in terms of degrees (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2016b). Our initial supposition is that the representations and language in *ScratchJr* supports the development of higher levels of mathematical reasoning for these young students by incorporating the turn coding block. This, in turn, becomes part of the more substantive overall programming instructions for the "Draw a square" task using algebraic logic.

Second, the way in which students engage in the task of drawing a square using *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) is vastly different from drawing a square on paper using a pencil and ruler. As students code the *ScratchJr* cat to draw a square, they are required to take the perspective of the cat (i.e. the square will be drawn in the same orientation as the cat is initially facing). Students who started their cat either facing up or down, or an alternative sideways orientation other than the cat facing directly left or right of the screen (student's perspective while looking at the screen), drew squares (if coded correctly) that looked different to the prototypical depictions of squares (parallel to bottom and sides of the screen).

This was evident in the student responses where they were unsure if they had still drawn a square for the reasons outlined above. While many students could code the *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) cat to draw a square, and thus meet DT curriculum outcomes, their limited mathematical understanding of "squareness" meant they were unable to reason if their shape was a square or not. This has implications in terms of a potential mismatch between the requirements of the DT curriculum—i.e. *program a robot to follow a path*—and spatial reasoning requirements of the mathematics curriculum where rotations and translations, implicit in this coding, are not developed until Year 5.

Finally, unlike the physical drawing of a square using a pencil and ruler, some students could see on the screen the "structure" of the square, i.e. the semi-concrete mathematical structure (Noss & Hoyles, 1996) of their drawing in the *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) programming code. This led five students, unprompted by the researcher, to identify units of repeat (e.g. move 100 steps, turn 90°) and then deducing that their code (move 100 steps, turn 90°, repeat four times) would draw a square. While, students in Year 2 should be able to identify a repeating pattern, this moves well beyond the typical linear patterns presented to students (e.g. ABAB). This led to students then deducing a generalisation for the perimeter (e.g. move *n* length, turn 90° and repeat four times) of the square and even further to discussions about measuring the perimeter of squares using the code (e.g. if my square has a length of 10 steps, the total perimeter will be 40 steps).

We suggest that these students were demonstrating early algebraic thinking (deducing patterns) and higher levels of spatial understanding and measurement (identifying the perimeter), beyond the current required curriculum standard (e.g. Year 6—*Continue and create sequences involving whole numbers, fractions and decimals and describe the rule used to create the sequence*; and Year 5—*Calculate perimeter and area of rectangles using familiar metric unit*s (ACARA, 2016b). Again, the mismatch between the curricula can be seen as a double-edged sword. In coding the *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) cat some students could arguably be seen as demonstrating very advanced mathematical thinking; however, at the same time, other students who managed the coding requirements of the task were clearly incapable of understanding the mathematical requirements of the task. The numeracy development of this latter group of students may be hampered if they are required to make connections between the simplified coding environment in *ScratchJr* with the much more complicated spatial reasoning requirements of the task.

8.10 Conclusion and Implications

The implementation of the DT curriculum in the lower primary years presents a challenge for generalist, early primary school teachers; both in terms of their discrete knowledge of programming and, perhaps more importantly, in terms of integrating this content within existing curriculum demands. This article has demonstrated that the two curricula in question, i.e. the DT and mathematics curricula, have not been as well matched as is necessary to fully develop synergies between the two. Whilst it is acknowledged that the Australian DT curriculum provides a much deeper level of content support than any of the other international curricula investigated in this research, this heightened level of explicitness is problematic when the more explicit content contradicts with explicit content in existing curricula, especially the mathematics curriculum. These contractions, missed opportunities and superficial connections result in the underdevelopment of the numeracy general capability that is meant to be an overarching concern of both.

In regard to coding more specifically, much of the past research in this area has only provided limited insights into how students use programming in the early and middle years of primary school, and even this research is inconclusive (Benton et al., 2017). This article adds to the current literature by indicating how the use of *ScratchJr* (DevTech Research Group, Lifelong Kindergarten Group & Playful Invention Company, undated) can assist teachers to support the development of programming knowledge in young students in such a way as to remain faithful to both curricula. Extant research with primary school students, when using robotics programs, have identified that young students develop numeracy skills as they use reasoning to problem solve (Savard & Highfield, 2015), in coding contexts.

Our early conjecture is that coding also provides an opportunity to identify and deduce patterns and is, therefore, a useful platform to encourage engagement with early algebraic thinking. Given the limited studies focusing on the classroom implementation of programming (Lye & Koh, 2014), and no published critical analysis of the synergy or otherwise between the DT and mathematics curricula in the Australian context, this research is an important contribution to the discourse. Although limited in scope, this research is an example of how the thoughtful combination of elements of both curricula can maximise opportunities for primary students to develop numeracy competencies requiring understanding of programming in authentic mathematics contexts.

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Chapter 9
'Quality' STEM Leaders in Remote Indigenous Contexts: Creating Pedagogical Capital

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Abstract Remote Indigenous education is challenged by many factors, one of which is the attraction and retention of quality teachers to work in hard-to-staff schools. In this chapter, I explore how successful remote schools have worked with the significant challenge of ensuring quality and rich STEM learning for Indigenous students. Building the skills of beginning teachers to work in these schools is the focus of this paper. The notion of pedagogical capital provides the tool for analysis. While this chapter draws on the examples from a comprehensive numeracy project, the principles, issues and outcomes apply to STEM education more broadly.

9.1 The Context of Remote Indigenous Education

Remote education is fraught with many challenges, most of which are documented across many years of research. For the purposes of this chapter, I will provide a brief summary of the diversity of research with the intent to provide a context. In this background, I focus on those issues associated with teacher quality in remote Indigenous education since building teacher quality through the creation of pedagogical capital is the focus of the paper. I draw on data from a national study across nearly 40 schools where many of the schools have developed a middle leader role whose primary task is the development of quality practices and quality teachers in those schools. While the term 'quality' is a contested one, it is used here to highlight the characteristics of good educators who work in challenging contexts.

I am creating a term—pedagogical capital—as a reference to Bourdieu's framing of the forms of knowledge and dispositions which he refers to as capital (Bourdieu, 1983). These knowledges and dispositions have particular exchange value within a particular field. In the context of this paper, pedagogical capital refers to the knowledges and skills that teachers need if they are to be successful in remote Indigenous education specifically but also more generally in education in any setting. These skills and dispositions may resemble some of those that are found in urban settings,

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but there are peculiar demands in remote settings that require different practices if there is to be success in learning STEM. The middle leader is a key variable in the building of pedagogical capital in remote Indigenous settings.

9.1.1 Teacher Quality: Transient, Tourist Teachers

Many of the teachers who come to teach in remote areas are early in their career so they lack the experience of both teaching STEM and are often in their first position in a remote/Indigenous context. Most employers recognise the importance of mentoring for early career teachers with most statutory-employing groups offering some form of mentor to beginning teachers. This is not so easy in the remote context where often most teachers are at the early start of their careers, and in some cases the principal is equally early in her/his career. This begs askance as to how, at a very practical level, can beginning teachers develop the repertoire of skills, knowledge, dispositions and resilience needed to survive and thrive in remote contexts. For early career teachers to lead others can be problematic when they do not have an extensive toolkit for professional learning of others (Borko, Koellner, & Jacobs, 2014). Teaching in remote schools places considerable pressure on teachers and school leaders as they negotiate the environmental and emotional challenges of living in remote isolated areas (Jarzabkowski, 2003). There are some authors who question whether too much is asked of early career teachers in remote contexts and that, in fact, employers may be putting too much reliance on the personal resilience of teachers as they enter these 'hard-to-teach' schools (Sullivan & Johnson, 2012) rather than building the skill set of teachers to be able to work effectively and productively in these contexts.

The pressure on teachers in remote (and rural) settings often results in a high turnover of teachers. In some states, the contract for teachers may be between 1 and 3 years. This high mobility or transience results in perceptions held by community members of the teaching staff (Mills & Gale, 2003), often where there is a high degree of skepticism as to the teachers' commitment to the school and community.

There are many motivations as to why teachers seek to work in remote areas. In a study of teachers working in a remote region of northern Australia (Jorgensen, Grootenboer, & Niesche, 2013) it was found that the motivations varied from adventure, travel and missionary with only one teacher (out of 32) identifying a socially-just motivation to working in the context. Similarly others (Schulz, 2015) have found the unwitting complicity to the three Ms[1] and tourist discourses for motivating teachers to work in remote desert contexts. As some (Hickling-Hudson & Ahlquist, 2004) have argued, the inexperience of neophyte teachers places them at greater risk of implementing reproductive pedagogies, vis a vis neo-colonial approaches and thus expose students to a Eurocentric curriculum that may contribute to the alienation and marginalisation of Indigenous learners.

[1]The three Ms are a reference to "missionaries, mercenaries and misfits" as the people who opt out to live in remote, harsh contexts.

9.1.2 Culturally Inclusive Practices

As the contexts within which the study was being conducted were very remote, the culture/s and language/s often were still very traditional. For many students, coming to school represents a strong cultural dissonance between the home and school. There are numerous studies and philosophical writings of the value of including approaches that advocate a culturally inclusive approach. Such approaches are quite diverse ranging from those that are ethnographic in standpoint and seek to build the cultural knowledges and practices into the existing mathematics curriculum, or in some cases to become the mathematics curriculum. Examples of this type of work are evident in the ethnomathematics tradition where there is a celebration of the mathematics embedded in cultural practices of non-dominant cultures (Rosa & Orey, 2015). There have been explicit attempts to seek the mathematics undertaken by Indigenous Australian communities and then incorporate this into a revised mathematics curriculum (Watson & Chambers, 1989). Similarly, the science aspect of Indigenous cultures can be incorporated legitimately into the curriculum. Fasasi (2017) reported that incorporating ethnoscience perspectives into the classroom can enhance learners' knowledge and attitudes towards science. While others have used more situated learning of activities to incorporate both the science and technology aspects of STEM (Nuroso, Supriyadi, Sudarmin, & Sarwi, 2017), other approaches have sought to identify more subtle aspects of culture and recognise how these impact on learners as they negotiate the taken-for-granted social and cultural norms of classrooms (Malin, 1990). For example, arising from this project, the issue of shame as a cultural construct was noted by many of the teachers in the study as impacting on the lives of learners (and teachers) in the schools (Jorgensen, 2018). These approaches adopt a strong care factor and seek to build into the programs' elements of culture/s that will enable students to feel validated and included in the classroom practices (Savage et al., 2011), and in so doing, sustain cultural pluralism (Paris, 2012). The culturally inclusive/responsive approaches often lack strong, effective and practical examples for educators and often at risk of not having the potential impact that the theory suggests (Griner, 2012). There is risk within these approaches, as cautioned by Nakata (2003), that can engender the educational context being subverted for the cultural or anthropological discourses and thus serving as a convenient rationale for the failure of those intended to be beneficiaries of the approach. The vast literature on mathematical content knowledge and pedagogical content knowledge has shown that teachers who have strong knowledge in one or both of these areas are more likely to produce better learning for the students (Baumert et al., 2010; Campbell & Malkus, 2014).

One of the major issues in remote education is the tyranny of distance and how this impacts on the possibilities for teachers' learning (Parding, 2013). It has been found that teacher support is critical for beginning teachers and the resultant quality of their teaching (Blömeke & Klein, 2013). Most communities do not have access to relief teachers who could come into the school and relieve a teacher to undertake external professional development. The distance itself also represents a significant issue. At best, there is a day travel each way to attend professional development outside the school. Alternatively to bring in external people to conduct professional learning requires additional travel costs for the consultant—both temporal and fiscal. As most remote schools are isolated, it is just as problematic to link schools to provide professional learning opportunities. Finally, accessing online resources may seem to be a good option but most schools have unreliable satellite Internet which will fall over on cloudy/rainy days to the point of not even working, the cost is extremely high for downloading, and the bandwidth is limited so that high-resolution video is almost an impossibility to download. Collectively, these issues provide challenges for schools in terms of professional learning, particularly for new graduates and/or teachers new to remote education. Models for professional learning that cater to the nuances of remote professional learning are needed.

9.1.3 Numeracy: Key Learning Area of STEM

For most remote and very remote schools, literacy and numeracy are key learning areas that take a priority in curriculum offerings. Most schools in the Remote Numeracy Project (Jorgensen, 2018) (which is the basis of this chapter) structure their day around three sessions. The order may vary, but predominantly the first session of the day is literacy, the second is numeracy and the third is all other curriculum areas. STEM education in these contexts may see science and technology being taught as part of the third session or integrated into numeracy and literacy. Digital tools provide strong engagement among Indigenous learners. As will be discussed in one of the later sections, digital tools are an integral part of the numeracy lessons. This process not only gives a high priority to literacy and numeracy but in most cases the lessons are in the first part of the day so that quality learning time is allocated to the two key areas.

9.1.4 The Outcomes of Remote Indigenous Education

There is widespread recognition of the educational chasm in achievement for Indigenous and non-Indigenous students. It is not possible to make sweeping comments since other factors impact on success including geographical location, social status, gender, language, etc. What is very apparent is for Indigenous students living in remote and very remote locations, there is a marked gap in achievement. To this end, successive Federal governments from 2007 have implemented the ‘Closing the Gap’ initiative which seeks to lessen the gap in health, education and housing for Indigenous people in comparison to non-Indigenous people (Australian Government: Prime Minister and Cabinet, 2016). Despite considerable funding being allocated to education through the funding associated with Closing the Gap, it appears that there has been little change in educational achievement (Taylor, 2016). While educational outcomes are important, other authors (Yeung, Craven, & Ali, 2013) have explored the nexus between academic scores in literacy and numeracy with self-concepts, self-ratings of schoolwork and learning-related factors for Indigenous and non-Indigenous students. They reported that Indigenous students reported much lower scores than non-Indigenous learners thus suggesting that schools need to focus on academic as well as factors associated with enjoyment of school life.

9.1.5 Moving Forward: Building Pedagogical Capital

Building scholastic capital, that is, the capital that has value within the field of education (Jorgensen & Sullivan, 2010), through education underpins the purpose of schooling. Investing in education allows students to build better lives in the future. Whether this is seen as an overt principle or a tacit assumption, it is without doubt the key purpose of schooling. Yet, what is known is that the gap between Indigenous students and non-Indigenous students, most notably those living in remote and very remote settings is alarmingly worrying. Many strategies have been developed, some of which were discussed earlier but mostly emphasise the importance of quality teachers (Pearson, 2009; Penfold, 2014). Winheller, Hattie, and Brown (2013) have concluded that 'the perceived quality of learning is connected with "confidence in" and "liking mathematics", which in turn predict students' mathematics achievement' (p. 49). Their work across a number of publications emphasises that the teacher is the most important variable in students' success despite some criticism around methods as to how Winheller and co-researchers were able to make such claims (Ingvarson & Rowe, 2008). It is generally accepted by employers that investing in teachers is a positive step in building the capacity of both teachers and students.

The remainder of this chapter explores how professional learning is undertaken by a number of remote schools in this study. More than half of the schools in the study had a nominated person to lead reform at the school level and to support teachers to develop their pedagogical capital. Across this study, it was the case that teachers were generally new to teaching and that accessing professional learning can be a drain on teachers in terms of travel time and time away from the class; and that there are no replacement teachers in the schools/communities so any professional learning absences are absorbed by other teachers in the school; and that it is very costly to bring in external providers to the school; and hence models of teacher learning are needed that cater for these unique circumstances. This situation is not unique to this study. In such contexts, the challenge is how to build the pedagogical knowledge and skills of early career teachers whether they are new to teaching and/or remote education. Creating opportunities that enable teachers to build their repertoire of skills, knowledge, dispositions, and cultural knowledges are paramount to building success in these contexts.

9.2 The Remote Numeracy Project

The Remote Numeracy study used an ethnographic case study approach designed to document the practices of schools that were experiencing success in the teaching of numeracy/mathematics to Indigenous learners. Success was defined in the study through outcomes from national testing that were published on the MySchool website (ACARA, 2019). For inclusion schools needed to have regularly scored above or greater than similar schools over time or been seen to be on an upward trajectory with their scores. There are limitations to this approach that are associated with the validity of the tests per se but as the only recognised and standard test available to researchers, *National Assessment Program—Literacy and Numeracy* (NAPLAN) data provided a common benchmark for inclusion. Schools could also be recommended to the team as often successes cannot be measured through tests such as the National testing scheme. In all cases, schools also provided school-based data on their successes.

9.2.1 The Sites

For inclusion, schools needed to be classified as remote or very remote on the Australian Curriculum, Assessment and Reporting Authorities' criteria. A school was listed according to its geographical location on the *MySchool* (ACARA, 2019) database so this was a readily and publicly available information. The schools needed to have populations with more than 80% of indigenous students attending, again with this data being available on the profile of individual schools. Across the sites, schools were included that covered all years of schooling—early years through to senior years (including Vocational Education and Training); all systems (Government, Catholic and Independent); schools of various sizes ranging from single teacher schools through to multi-campus sites; and included all states and territories that have remote and very remote schools. A summary of the published case studies can be seen in Table 9.1 below where the types of schools can be seen.

Table 9.1 Published case studies

	Government	Catholic	Independent	Total
Western Australia	11	3	7	21
Queensland	5			5
South Australia	4			4
New South Wales	5			5
Northern Territory			1	1
Total	25	3	8	36

9.2.2 Method

The study was ethnographic in design and sought to develop case studies of each school (Jorgensen, 2016) that described the practices adopted by the schools. Data consisted of interviews with leaders, teachers and other staff at the school, classroom observations and document analysis. The process was designed to meet with the school leaders at the initial point of contact to gain the 'big picture' of the school and then to work with other staff and affiliated people to see alignment between the vision of the school and the practices and articulations of staff. At the completion of a site visit, a case study was developed that drew on the alignments between the vision and the practices. The case studies were provided to the schools for feedback and any points of clarification before they were published on the project website.

Ethics approval was granted to name the schools on the published website as requested by the schools. All other publications comply with confidentiality with names and identifying information to be deleted from reports to protect the identity of schools and participants. A total of 39 cases were developed and published. Four other case studies were undertaken but for various reasons were not published.

All interviews are recorded, transcribed and coded using NVivo (QSR, 2010). Data were also entered into Leximancer which is a computer program to analyse text about content and key words. The data generated from Leximancer was used to cross-reference between the coding in NVivo to validate (or not) the coding categories. There were strong synergies between these two processes so there is a high degree of confidence in the coding process in NVivo. The data presented here draw on the NVivo node relating to middle leadership.

9.3 Building Pedagogical Capital Through Middle Leadership

Many of the schools have adopted a devolved model of leadership, particularly in schools where there were comparatively large numbers of teachers. Many schools across the study have adopted a role within the school whose task was to build the expertise or capital of the teachers in mathematics; to foster the development of a whole school approach; to provide support for the teachers in many areas including feedback on lessons, advice on assessment, interpretation of data; build a whole school plan for mathematics; and to liaise between the leadership team and the classroom teachers. Across the schools, the title of this position varied, but for the purposes of this paper, I have opted to adopt the term 'Numeracy Leader' for this role. As the project focused on numeracy practices, the data reflect this focus. In the following sections, I draw on participants' voices to highlight the role and value within the remote Indigenous context.

The notion of a middle leader is critical in the context of remote education for many of the factors cited in earlier sections of the chapter, where schools are unable to release teachers to attend professional learning opportunities due to the tyranny of distance and/or the inability to cover teachers' load while they are absent from the schools; a model of professional learning is needed to enable the building of teachers' professional capital.

9.3.1 What Is a Middle Leader?

For the purposes of this project the middle leaders are those teachers who have been taken out of class to provide support to the peers while also liaising with the leadership team of the school to ensure that the vision of the school is being enacted through the support being provided to the teachers. The middle leader becomes a conduit between the school leaders and the teaching staff.

Such roles may be adopted in other systems, including urban settings. The difference with the remote context is that their role not only focuses on the standard practices found in urban and regional settings where there are systemic initiatives that need to be enacted, the remote context also requires the middle leader to have some awareness of culturally sensitive practices and a working knowledge of the wider community that the school serves.

9.3.2 In-class Support to Build the Pedagogical Capital of Teachers

Across the schools that had adopted the role of middle leader, there was a general consensus that the in-class support was a valuable role in building the culture of the school and the expertise, or pedagogical capital, of the teachers. With so many of the staff being new to teaching, their repertoire of skills was relatively limited. The importance of mentoring new teachers is well documented (Hobson, Ashby, Malderez, & Tomlinson, 2013; Ingersoll & Strong, 2011) but the capacity to provide mentoring in remote areas is limited for the range of reasons cited at the beginning of this paper. The Numeracy Leader had a critical role in supporting beginning teachers in their professional learning; their induction into the profession as well as the induction to living in a remote geographical location with diverse cultures and languages.

The types of support that were offered in the classroom varied across the study, and included feedback on lessons, co-planning with the teacher, developing tests/assessments and then interpreting the data to inform subsequent teaching and modelling teaching, along with tasks that the teacher and/or school saw as valuable. There were also practices related to the culturally responsive aspects of teaching in remote areas. The role of the Numeracy Leader also included the support teachers in the interpretation of their student data and then to build appropriate learning interventions to support students' learning.

> Numeracy Leader: My approach was a lot more practical. We did, "they observed, we observed". This tends to be our approach. So this week I've been demo-ing explicit lessons to the new teachers. I'll come in and watch then next week they get observed and get feedback on it. So it's about that and then we did P.D before that so they get P.D they are watched in action and then they are observed to give feedback and that's part of the whole school approach. … I would say last year we were really, those teachers moved fast, very quickly last year and I reckon by week 5 she was confident but there are some teachers that don't cope and find it a bit harder.

The role of the Numeracy Leader varied. In some cases, the leader would work on a regular basis with the teachers, often taking small groups of learners or working with targeted students in either extension, remedial or general small group contexts.

> Numeracy Leader: They [teachers] had a support teacher every day for maths. We also had a numeracy specialist that would be coming in and that was part of my role as a Year 1 support. I would take out a group of the lowest children and I'd be responsible for doing their numeracy learning for the year.

In other cases, the Numeracy Leader would support the teachers in their planning, teaching and assessment. For new teachers, planning is a valuable tool so the Numeracy Leader not only could help the teacher plan but could also ensure that the planning aligned with the intended goals of the school. In the data-driven world of contemporary teaching, teachers were also expected to undertake considerable assessment of learners. The Numeracy Leader played a role in supporting teachers to interpret their data and to develop strategies based on that data.

> Teacher: [name] used to be our maths specialist but now we don't have that any more. That was good having her because she was timetabled into help you as well during maths. During the term she'd be like, 'alright for the next two weeks I'm going to support you and help you with your programs' and she'd move around the school … She'd sit down with me and we'd write our whole term program together and pick out what we needed to do. We'd look at the kids' data that we'd take from diagnostic tests and stuff and decide what we needed to target and look through the curriculum and come up with our plans. She used to do that with everyone.

Teachers also commented on the role the Numeracy Leader had in supporting them to work with the cultural norms of their classrooms.

> Teacher: I needed support in helping me work with the children so that they were not shamed. When [name] would come into my class she would model how to incorporate things into my teaching so that the children felt included and not upset. For example, rather than ask the children if they like something, she modelled the thumbs up - thumbs down so I could see how they were feeling but without being ashamed of how they felt. It was simple and easy to do but I didn't know about it.

Across the study, the in-class support was seen to be the most valuable aspect of the Numeracy Leader's role in the school. As shown, these roles varied but the day-to-day interactions, in the classroom, were highly valued as they provided an immediacy and very practical support for the teachers.

9.3.3 Working with Community

The role of the Numeracy Leader in remote communities extended beyond the boundaries of the school fence. The Numeracy Leader often would work with the early years settings so as to establish relationships with the children and families but also to gather information on the children who would be coming into school in the coming year. Such data were invaluable in supporting the teacher working with the children when they entered school.

> Numeracy Leader: I was going out to [name of community], they've got an early years centre out there as well so I worked with those kids as well. So helping the teachers plan and assess lessons and then I'd also go in and support them. Collating the data and analysing data to keep passing on to the teachers the following year.

While this case highlighted the need to build relationships outside the school fence, there were other sites where the early years centres were within the school grounds. The role of the Numeracy Leader was important to identify the scholastic capital—whether mathematics or STEM—of the young learners so that the teacher would be aware of the learning needs of the incoming cohort.

9.3.4 Co-planning and Co-teaching

Supplementing the in-class support, the Numeracy Leaders often worked very closely with the teachers to build their planning documents and assessments. The Numeracy Leader often would team-teach with the teacher. In some cases, the Numeracy Leader acted as a support person in the classroom to help with the diversity within a classroom, in other cases to model teaching for the teacher.

> Teacher: So we'll sit down and we'll do it together. Like, so she knows that, you know, we'll work off my term planner that we've got, and I know that on those 2 days I wanted to do time and yeah, so that's what, so I use that. And so we'll sit down and we'll just go through the First Steps books and we'll find some activities that will help the kids reach it. … [B]ecause there's so many kids in the class and they're quite needy, [name] usually comes in and we team teach.

With the Numeracy Leader coming into the classroom in a very hands-on role, the teacher is building his/her repertoire of skills and knowledge. The Numeracy Leader had a strong sense of the class through their in-class support so was well placed to assist in targeted planning.

9.3.5 Planning and Implementing a School-Wide Approach

In some schools where there was a common approach across the school, the Numeracy Leader was able to model that approach to the teacher. For example, at one school, there was a school-wide model of teaching. The school had a two-hour numeracy block each day. The block consisted of four different activities—a warm up where the learners would practice fast-paced, recall type activities aimed at building fluency with number. The second section of the lesson focused on revision of concepts covered so that learners were constantly reminded of what they had been learning. One of the 'reminders' in this session was also a priming activity for the next section. This meant that, for example, if the lesson was on fractions, then there would be activities around fractions so that the learners had been primed for the conceptual learning that was to follow. The third section of the lesson was what might be loosely referred to as a typical teaching episode in which the teacher would conduct the didactical process aimed at learning or consolidating some specific concept. The final section of the lesson usually included digital tools for learning. As such, the Numeracy Leader would work closely with the teachers to develop this whole school approach and to follow the principles that were integral to the various sections of the lesson. This whole school approach started in the early years and has progressively moved up with the children. So, after 7 years, the approach had been embedded across the primary years of schooling and was being considered for adoption across the secondary years at the time of the data collection.

> Numeracy Leader: It is important that we get all the teachers on board with our school's approach so a key role for me is to induct the teachers in the model. We have a week induction at the start of the year where they learn about it. But if we know who's coming to the school before then, I would send them information prior. I provide them with a unit of work for the first month then they don't have to plan anything, just practice and put things in place. That helps them a lot. And then once they start teaching the unit, I come into the classroom and support them. Either I model and they observe, or they teach and I provide feedback. This works well and they learn a lot.

The Numeracy Leader articulated the process used by the school to build the teachers' skill base or pedagogical capital. Across the schools in the study, similar processes were used by the Numeracy Leaders, but the most common were either modelling processes to the teachers or observation/feedback cycles. The Numeracy Leader had a critical role in the roll-out of school-wide initiatives whether they were a whole school approach or particular strategies that were seen to be valuable for the context of the school.

Many of the Numeracy Leaders were supported by their systems. The Independent Schools of one state had built a model for remote education where there was a Coordinator who would regularly visit the schools (usually once a term) and work with the Numeracy Leaders on building their skills and knowledge in both mathematics education as well as leadership. The consultants worked in a face-to-face context but also provided support remotely. If a Numeracy Leader needed advice on how to support a teacher, the consultant was available for support. This model was very supportive for building the capital of both the Numeracy Leader as well as the teachers. Similar models existed in other systems and states to varying degrees.

> Numeracy Leader: I don't know what I would do without {name]. She comes up here regularly and if I need to know something, I can call or email her anytime. She is a lifeline as she know so much.

> Consultant: I find that my role is to extend the Numeracy Leaders in their mathematics education so that they can help their teachers. Also, to support them in issues around leadership and managing their teachers.

While the Numeracy Leaders served a critical role in the schools, they also needed support to build their repertoire of skills in mathematics education (and STEM), as well as their knowledge in cultural pedagogies and working in a leadership role. Depending on the school context, this level of support would vary. In some schools, the middle leader was a highly accomplished leader in curriculum, whereas in one case, the Numeracy Leader was a relatively new to leading role.

9.3.6 Building Deep Mathematics

As is well known from the research literature, many primary school teachers have low Mathematics Content Knowledge (MCK) and often are fearful of teaching mathematics. Building MCK in both teachers and students is empowering and has been a part of many schools' professional learning. Many workshops were held that focus on the learning of mathematics, and this in turn has helped teachers build the mathematics learning for their students. In the context of remote teaching, deep mathematical knowledge is important since many teachers are teaching out of field, or may be fearful of mathematics. Such a situation can engender the risk of deficit teaching so that the Indigenous learners are not exposed to the richness and beauty of mathematics or interaction with STEM more broadly.

> School Leader: We were very concerned when we arrived at the school that students in the high school classes were receiving a very impoverished maths. The teachers didn't realise that they were not extending the learners, instead, they were giving them basic maths. Really, if you keep giving the kids the same Grade 2 maths for years on end, and they don't get it, teachers need to have other strategies to build mathematical ideas. But to do this, THEY need to know maths themselves. So we have spent a lot of time building mathematical knowledge with our teachers - primary and secondary.

> Numeracy Leader: Teachers need to know their maths. So, we have had a lot of workshops just on maths. It helps them to be more confident in their teaching as they know the maths and not scared of it.

Teachers recognised the importance of building deep MCK in their learners and the processes through which this can be achieved.

> Teacher: …we've got our numeracy coordinator, … but she works very closely with teachers to ensure that mathematical understanding has been developed in the kids not just, like I was saying about the fractions, not hollow, there's a depth to it.

Having strong curriculum knowledge whether in mathematics per se or across the STEM disciplines is important for deep learning. Having processes to keep developing the content knowledge of teachers is important, particularly in the STEM areas where many primary teachers do not have strong content knowledge.

9.3.7 Professional Learning

The Numeracy Leader has a role in the professional learning of the teachers. This was undertaken in many different ways across the schools—after school sessions, in-class in real time, professional reading, mathematics activities, and so on and largely based on the needs of the teachers and the vision of the school.

> Teacher: We've had a lot of PD and how to develop appropriate, well not appropriate, it's sort of like a bit of a developmentally-appropriate maths lesson to really get these kids moving from what they were doing before [the Numeracy Leadership team] got here to now and it really has deepened the whole understanding.

> Numeracy Leader: I have to work with the teachers to build their knowledge skills as well as ways on how to teach in these contexts. I try to do some of the cultural knowledge as well. Being aware of how the kids are socially and culturally is important. Teachers need to know that things like shame is a very big issue in these contexts so they have to find ways to work with it.

Depending on the school, the Numeracy Leader often worked with the Aboriginal Education workers as well to build their knowledge—both mathematics and pedagogy so that they would be able to be a valuable resource in the classroom.

> Numeracy Leader: It is important to work with the local teachers. After all, they are the ones that will still be here after we go. They have seen so much come through the school. They know what will work and what won't so we should draw on that rather than keeping investing in things that haven't worked in the past.

> Teacher: We have a culture here we our local people are our teaching partners. The numeracy coach works with them as well. Often they get different workshops so that they have a backpack of ideas that they can use in the classroom. These help when they are working in small groups with the kids.

The professional learning of the staff—teachers and local teachers—is a key role of the Numeracy Leader.

9.3.8 Building a Whole School Approach

As noted in an earlier section, there is strong sense across the participating schools of the need for a whole school approach to teaching numeracy/mathematics. The Numeracy Leader had an important role in building that culture and the knowledge within the teachers on how to teach mathematics at the school/s.

What was subtle but important feature of the planning models used across many of the schools was their awareness of the need to build practices to support learning of the Indigenous students. In the remote communities, mathematics and STEM used in schools are not commonly practiced in out-of-school contexts. Taking the example of fractions as an exemplar, Indigenous students have different experiences of sharing so the notion of 'half' maybe conceived differently from that used in school. Sharing is often based on status within the group rather than being ‘equal’ as represented in school knowledge.

It was the role of the teachers and Numeracy Leader to create experiences that traverse these differences. In his extensive work on automaticity, Pegg and Graham (2013) showed the importance of activities to build automaticity and fluency with numbers for Indigenous learners. The need to refresh learners’ thinking about fluencies and competencies as well as knowledge constructs was foundational to the learning models being used. The seamless transition between prompting learners with the goal to refresh their prior learning and then moving into the substantive part of the lesson was a unique part of many models used across the study.

All of the schools in the study made reference to have strong and high expectations of learners and to move away from deficit models of thinking and pedagogy. Building cultures that embody this philosophy were a critical part of the middle leader role. At the same time, the middle leader had to create opportunities for the teachers to build their repertoire of skills to enable teaching practices that did not fall into deficit models of thinking.

> Leader: One of the things that I have had to do at the school is to build my teachers’ understandings of how to extend their students. They have to start with the thinking that if these students are in Year 10, then they should be getting Year 10 content. It is not sufficient for them to keep teaching the same things for 6 years and the students can’t do it. It means we have to break away from that old thinking that knowledge is a continuum and if you don’t get something in Year 2, you have to keep doing it until you do. So, my role is to challenge that thinking and create opportunities for the teachers to develop other strategies to support their students.

Having a whole school approach had many benefits. These included, but not limited to, having consistency across the school; allowing teachers to engage in common conversations and to support each other; ensured that families had a familiar view of the school; ensured that learners knew what would be happening in their mathematics lessons and allowed for professional learning of teachers and ancillary staff to participate in shared professional activities.

> Principal: I think the whole school has to work on being on the same, have the same vision and we got new staff so perhaps that will take time.

Having a shared approach to curriculum, pedagogy and assessment also enabled principals to promote their schools as being of a particular ethos and facilitated targeted recruitment. As one principal indicated to incoming staff that if they did not like the school’s approach, then they should consider employment elsewhere.

> Principal: Teachers are aware when appointed [to the school] what program we use. They get lots of info about the program, and support. Numeracy coordinator gives less time to experienced teachers, and more time to new teachers, initially.

9.3.9 Working with Indigenous Knowledges and Languages

Across the STEM areas, Indigenous people have different ways of seeing, viewing and interacting with knowledge systems. Whether these are mathematical or scientific, finding ways to incorporate (and legitimate) these knowledge systems into the school experiences are invaluable for Indigenous learners. Not only does it create bridges between the two world views, and thereby validating indigenous knowledges, it offers ways of incorporating the skills and knowledges of the local people. Having local people employed at the schools is one way in which these perspectives can be included in the learning experiences.

> Teacher: Our aides know the community, they know the country. They can bring ideas and language to the classroom that help the kids. My aide is amazing. Sometimes, the kids don't understand me so she just steps in and explains it in Kriol and then they get it and can move on.

> Teacher: I rely on my teaching assistants to provide the students with ways of accessing the maths and language and what I am trying to teach. She can say it in home language but also give examples from their homes.

Knowledges, ways of seeing and acting in the world and language are important in the learning process but with so many teachers staying relatively short periods in remote communities, the local people are the backbone of education. Their role in supporting, informing and planning with teachers helps to build the bridges between the hegemonic Western curriculum and the knowledge systems of the local communities.

It is important for the teachers and staff to identify community life and events in their examples. In one school, a teacher drew on his knowledge as a ranger to link to the home lives of his students.

> Teacher: The kids here love fishing so I have drawn on that knowledge. We look at the fish you find in the river here and their lifecycle; we talk about size of the fish; the gear you will need to hook one. All that sort of stuff. The kids love it and get right into it as it make sense to them.

> Teacher: I found that one of the things here is that they sometimes don't understand the environmental impact that introduced species have on the native animals. We caught a feral cat and looked at its stomach contents. They could see all the animals it had killed and eaten. So it was a bit of science and maths together.

Involvement of the local people required the teachers to develop a good relationship with their local people—both in and out of school.

9.3.10 Funding the Role

Within Indigenous education, funding is provided to the schools via the system or in the case of Independent schools, through a budget. As with education as a whole funding can be quite fluid. In one year of the study, there had been a change of government which resulted in a radical change (reduction) in funding. This meant in most cases, schools lost significant funding. As a result, budgets had to be changed, priorities identified and reorganisation of the schools as a result. In some schools, this had an impact on the role of the Numeracy Leader.

> Numeracy Leader: So the school has had a numeracy coordinator, I've done it for the last year and ¾ and there was someone before that and someone before that. So it's been with three people. This year it doesn't exist because of funding <cuts> so we've lost that completely, so everything we've been trying to build up is sadly this year starting to fall down because we don't have that extra support.

Other schools have taken different steps. Rather than lose the role of the Numeracy Leader, the time allocation may have reduced, or in other cases, the school has made the radical decision to increase class sizes and free up a teacher to take on the role.

> Principal: We had to drop numeracy coordinator to 0.7, and coordinator has to teach, too. We've had to lose in other areas, but had to keep the numeracy coordinator because it's vital.

9.4 Summary and Conclusion

In summary, the role of the Numeracy Leader is quite diverse. Having a person based within the school ameliorates many of the issues identified in the literature in terms of supporting teachers in remote contexts. Having the Numeracy Leader based at the school meant that the support was in situ and readily available. This was particularly important in remote contexts where travel is prohibitive in terms of costs and time.

As shown in the preceding sections, the role is diverse as shown in the previous sections. The role can be summarised as:

> Numeracy Leader: [it's a] Mentoring role. I'm not expert in anything. Try help them develop further understanding in all areas of maths; providing them with good assessment items; showing them how to use it to inform teaching; keep them enthusiastic; be ready to go in and model (not just talk the talk); trying to show staff the way you can show kids how to pick up patterns (because maths is all about patterns).

An important attribute of the Numeracy Leader that cannot be underestimated is their familiarity with working in remote contexts. The nuances of remote teaching to which I alluded in the earlier sections of the chapter shape the possibilities of teaching and learning in these contexts. The Numeracy Leaders were all teachers who had experience in remote education and brought this to their work.

> Numeracy Leader: There are a lot of things that you need to be aware of when you work in these places – truancy, poor health, families and what is going on in community. Then they need to be able to work alongside an Aboriginal person as their support teacher. I've been there and done that, so I know what the teachers need to think about. I think that helps too.

While the Numeracy Leader role was overall seen as a very positive one for so many reasons, the characteristics of the person in the role are very important. While in most cases, the teachers and leaders were very positive about the role and the appointees, there was a case where the teachers were somewhat circumspect about the person. This was largely due to the person also being an early career person (3 years since graduation) and did not have the repertoire of skills, knowledge and classroom experience to be able to support the teachers in a genuine and deep way. Overall, however, the Numeracy Leader role has been instrumental at many of the schools to build a whole school approach but also to build a positive learning culture among the staff.

> Principal: So you're seeing similar practice being used across the board. And a lot of it is good discussions too. You know, we'll often have that chance, let's just have a brainstorm on sharing some good practice together. Or after our staff meetings, we're all held in our meeting room, and after we developed the, um, data wall in March this year, we found that that's really added to some wonderful discussions and people hanging around after staff meetings to talk.

Having the right person in the role as a Numeracy Leader enabled schools to address many of the issues that are commonplace across remote schools. The schools in this project that have adopted the role of a Numeracy Leader have taken a proactive stance, often being quite creative in how they manage to fund the role, to ensure that teachers are able to access the support they need to build a comprehensive and cohesive approach to teaching mathematics. The processes described by the participants in the project elucidate the ways in which the pedagogical capital of the teachers and Aboriginal Education Workers can be built up (and sustained). What is clear from the work undertaken by the Numeracy Leaders is that through their role as a leader, they have been able to create circumstances to enable teachers, particularly those new to teaching and/or remote education, build their knowledge and skills and apply these to the teaching context.

While this chapter has drawn on the work of Numeracy Leaders and their practices that build the pedagogical capital of teachers, the principles identified can be readily applied to STEM education and the potential work of STEM middle leaders. Building STEM capability of both teachers and students is important, and the role of the middle leaders—such as a STEM Curriculum Leader—is a significant component in leading reform. This is particularly poignant in remote contexts where access to professional learning is challenged by the geographical distance and isolation of being remote. Having a key person in the school setting who can assume responsibility for staff development is an effective model for building capacity, or capital, of the teaching staff.

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Chapter 10
Exploring Student Views and Perspectives Within a Changing Classroom Context: Developing Mathematical Inquiry Communities with Diverse Learners

Jodie Hunter, Roberta Hunter and Rachel Restani

Abstract In many Western countries, an ongoing challenge for researchers and educators over the past decade has been persistent inequities in mathematics teaching and learning for particular groups of learners. A key issue related to equity is the exclusion of diverse learners' culture, language and ways of being within mathematics classrooms. Within the New Zealand context, there is a changing student population that is increasingly culturally diverse. New Zealand student backgrounds include indigenous Māori students as well as the largest group of Pāsifika students in the Western world. Frequently, within the schooling system in New Zealand, the cultural background of both Māori and Pāsifika students has been perceived as a deficit and these students are ascribed low status and given related repetitive and procedural teaching. This chapter provides an exemplar of a professional learning and development approach that draws on students' cultural and language backgrounds to induct the students into using a range of mathematical practices in the mathematics classroom. The chapter examines the changes in student views over one year beginning from the introduction of the strength-based approach. It uses the voices of diverse students to provide a window into understanding how such an approach can serve as a mechanism to support the development of a strong mathematical disposition as well as a positive cultural identity.

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10.1 Introduction

In many Western countries, an ongoing challenge for researchers and educators over the past decade has been persistent inequities in mathematics teaching and learning for particular groups of learners. Growing awareness of the gatekeeping role of mathematics on students' future education, employment and life choices (Hunter & Hunter, 2018; Tate, 2013) has resulted in a need to investigate and address issues related to equity within mathematics education. A key issue related to equity is the exclusion of diverse learners' culture, language and ways of being within mathematics classrooms (Battey & Leyva, 2016; Martin, 2009; Rogoff et al., 2017). Within the New Zealand context, there is a changing student population that is increasingly culturally diverse. New Zealand student backgrounds include Indigenous Māori students, as well as the largest group of Pāsifika students in the Western world.

Students of a Pāsifika background are not from a single ethnicity, nationality, language or culture but are a diverse group including those born in New Zealand who identify themselves with the Pacific Islands culture and language and those who have migrated to New Zealand from the Pacific Island nations (Coxon, Anae, Mara, Wendt-Samu, & Finau, 2002). Frequently, the cultural background of both Māori and Pāsifika students has been perceived as a deficit within the schooling system (Hunter & Hunter, 2019; Turner, Rubie-Davis, & Webber, 2015). For example, in a study by Turner et al. (2015), the researchers found that teacher expectations in New Zealand secondary classrooms were lowest for Māori and Pāsifika students. Teachers referred to perceived deficits in home backgrounds and attitudes of this group of students by stating that Māori and Pāsifika students lacked motivation, goals, aspirations and parental support. Similarly, in the mathematics classrooms in which we work, we have observed many instances of Pāsifika students' ascribed low status and related repetitive and procedural teaching associated with a Eurocentric view of mathematics. Teachers often implement rote practice activities instead of facilitating collaborative discussions that build on students' mathematical understandings and cultural strengths.

Civil (2016) argued that researchers should go beyond looking at where science, technology, engineering and mathematics (STEM) is in real life and instead look at non-dominant people's engagement in everyday practices (e.g. seamstress, carpenter). After analysing case studies with Latino students in the U.S., Civil found that mathematics and language that Latino families used outside of school were not recognised or valued as strongly as the mathematics or English language that is taught in school. This is similar to the mathematics Pasifika families use when designing tapa cloths or navigating boats via constellations (Civil & Hunter, 2015). Civil (2016) claimed that we need to better understand participation structures of non-dominant communities, specifically when and how people use languages in their home cultures and around mathematics.

This chapter examines the changes in student views over one year beginning from the introduction of a strength-based approach. This approach draws on the students' cultural and language backgrounds to induct the students into using a range of mathematical practices in the mathematics classroom. The chapter uses the voices of diverse students to provide a window into understanding how such an approach can serve as a mechanism to support the development of a strong mathematical disposition as well as a positive cultural identity.

The chapter includes a case study of four classrooms from one low socio-economic, high poverty, urban school in New Zealand over the first year of implementation of the Developing Mathematical Inquiry Communities (DMIC) professional learning and development (PLD) project. It draws on the voices of students from Year Five to Eight (aged 9–12 years old) and data gathered from both written questionnaires and small group interviews. The interviews were conducted in small groups of two or three students while the questionnaire was completed individually. Due to the ethics procedure, the questionnaires were completed within a month of school beginning, while the initial interviews were undertaken later in the year in May after the DMIC professional development had begun. Both the questionnaire and interviews were undertaken again at the end of the school year. In total, 91 students completed the written questionnaire while 44 students also agreed to participate in the small group interview including 22 male and 22 female students. The students were predominantly of Pāsifika descent ($n = 32$) with other students from an indigenous New Zealand Māori background ($n = 9$) and a small number from South East Asia and India ($n = 3$).

The purpose of the questionnaire and interview questions was to assess students' perceptions of mathematics and themselves as learners of mathematics. Following a grounded theory approach (Strauss & Corbin, 1994), we developed codes that described patterns as they emerged from the data. We used the same descriptor codes to analyse the data before and after teachers learned to facilitate inquiry communities. One questionnaire item is reported in this chapter:

> What is mathematics?

The chapter draws on six of the interview questions (a complete list can be found in the appendix):

> What makes someone good at maths?
>
> What would you need to do to get better at maths?
>
> Is it important for you to be able to explain how you solved a problem? Why?
>
> Is it important for you to understand how other students solved a problem? Why? How do you feel about asking questions in maths?
>
> How do you feel about disagreeing with people in maths?

In the next section, we outline the core components of the strength-based programme and how it differs from the mathematics the students have previously experienced.

10.2 Developing Mathematical Inquiry Communities

Developing Mathematical Inquiry Communities is a whole-school formative professional learning and development research project. It is implemented in schools that serve disadvantaged communities, most often with a high proportion of Māori and Pāsifika students. The DMIC project was designed as a transformative re-invention of pedagogical practices which incorporates ambitious mathematics pedagogy (Kazemi, Franke, & Lampert, 2009), culturally responsive and sustaining teaching (Gay 2010; Paris 2012), and many aspects of complex instruction (Featherstone et al., 2011). A key element of the DMIC PLD involves dynamic mentoring (Hunter, Hunter, Bills, & Thompson, 2016). The teacher and mentor work together to co-construct mathematics lessons which are comprised of both large and small group discussions. The students are structured to work collaboratively in heterogeneous small groups to solve problematic tasks. Cultural metaphors which align with the students' cultural background as Pāsifika or Māori learners are drawn on as a way to promote collaborative interactions. A key expectation is that students develop a jointly constructed solution which all students in the group can understand and explain and justify mathematically.

In most classrooms, having students work collaboratively in small heterogeneous groups and then explain and justify their reasoning directly contrasts with previous practices they have experienced. Most often, they have been in classrooms where teacher talk dominates as the teacher leads students to learn a range of specific numerical strategies (Anthony & Hunter, 2012). The students have been grouped by ability as advocated within the New Zealand Numeracy project (Ministry of Education, 2004). As a result, they may not have been exposed to challenging tasks, a wide range of reasoning, nor the need to sense-make. Within DMIC, the key components include the use of teacher-designed high-level challenging group-worthy culturally appropriate tasks; instructional practices that support students engaging in respectful social interactions which promote prosocial skills; and the development of a range of mathematical practices including providing mathematical explanations, mathematical argumentation and justification.

Mathematical practices, as a key aspect of students learning and doing mathematics, has gained increased attention over the past decade. Over time, many explicit links have been made to the deep connected mathematical understandings which emerge as a result of students participating in rich mathematical discourse (Hunter & Hunter, 2019; Wood, Williams, & McNeal, 2006). In more recent times, the focus has shifted from students not just participating in the discourse but rather on more specific forms of talk—those inherent in the discourse used in mathematical practices which support powerful reasoning (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Although there is a wide range of mathematical practices, there are some which are foundational for the use of others. A more specific example is that of making mathematical explanations which provides the basis for the development of a mathematical argument, justification and generalisations (RAND Mathematics Study Panel, 2003).

For some students, understanding and using mathematical practices is an implicit practice. However, engaging in mathematical practices is not something all students can do easily, for many students specific adult intervention and support is required. At the same time, consideration needs to be given to the values and beliefs of many diverse learners. For Pāsifika students, disregarding their values and beliefs often causes them a high level of discomfit and their potential withdrawal from mathematical activity (Hunter & Hunter, 2019). Within DMIC direct teacher actions, both culturally responsive and culturally sustaining teaching, are used to ensure that these students are not precluded from questioning, challenging and engaging in mathematical argumentation (See, Hunter & Anthony, 2011; Hunter & Hunter, 2018, 2019). The use of a smart tool, a Communication and Participation Framework (For more information on the Framework see Hunter & Anthony, 2011) provides both communicative and performative actions, available for teachers to use flexibly to induct their Māori and Pāsifika and other diverse students into the use of a range of mathematical practices. Importance is also given to teachers explicitly scaffolding student use of questions to elicit further explanatory information or justification of reasoning.

The DMIC strength-based approach to problem-solving resembles researchers' call for more mathematics education in STEM research. Mathematics education substantially fortifies each of the STEM disciplines via problem-solving and logical reasoning in real-world situations (Johnson, 2012). Likewise, mathematical literacy, as defined by the STEM Task Force Report (2014) in the U.S., was defined as such:

> *Mathematically literate* students not only know how to analyze, reason, and communicate ideas effectively; they can also mathematically pose, model, formulate, solve, and interpret questions and solutions in science, technology, and engineering (p. 9).

Mathematical reasoning is embedded within each of the STEM disciplines just as each of the disciplines are connected to mathematical fluency.

English (2015) described examples of students in Cyprus and Australia who modelled with data. She argued for more research exploring the mathematical component of STEM because using mathematical models to analyse data is an important aspect of Engineering. Similarly, the sciences and technology require mathematical problem-solving and inquiry. Despite the importance of mathematics in each of the STEM disciplines, there is a lack of research acknowledging the mathematics within STEM. Specifically, many engineering articles focus on the connection to the sciences and only 16% of articles presented at the 2014 international STEM conference focused on mathematics.

Additionally, Ferme (2018) found that both STEM and non-STEM teachers in Australia believed that numeracy plays an important role in people's everyday lives. The Australian Curriculum and Assessment Reporting Authority (2013) defined Numeracy as being able to use mathematics in the world and across learning areas. Ferme advocates for non-STEM teachers to develop their confidence in mathematics so that they can better support their students in developing numeracy. We build upon the call for more mathematics education in STEM research by describing students' perceptions of mathematics in inquiry-based classrooms.

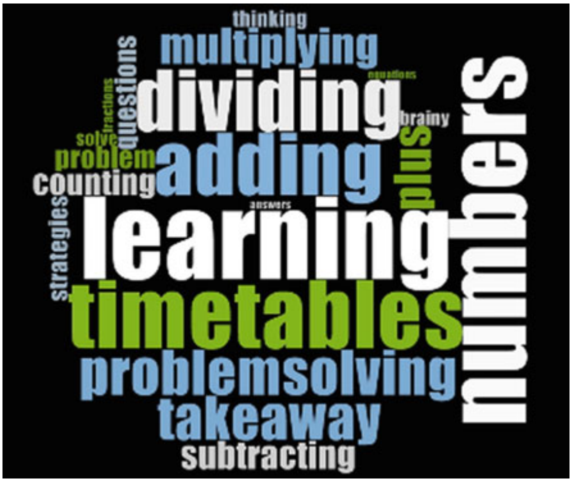
Of importance in this chapter is the effect on students when teachers ensure that they all have opportunities to participate and engage in these mathematical practices. While a number of previous studies (e.g. Hunter & Hunter, 2018; Kazemi et al., 2009) have focused on the role of the teacher in shifting pedagogy towards ambitious practice, fewer studies focus on student perceptions in changing classroom contexts. For students inducted into reformed classroom communities such as in DMIC, there are shifts in their role as a learner. Students are required to engage in ways of learning that privilege both different forms of knowledge and participation (Hodge, 2008; Hunter, 2017; Pratt, 2006). The focus in this chapter is an exploration of diverse students' perspectives over the school year related to learning mathematics in their changing classroom context. To do this, we investigate students' initial views and contrast this with student perspectives at the end of a school year after their teachers had participated in the DMIC professional learning and development project and been implementing DMIC aligned pedagogy in their classrooms.

10.3 Student Perspectives on the Nature of Mathematics

For many years, the nature of mathematics and student/teacher views of mathematics has been a focus of mathematics education research (e.g. Di Martino & Zan, 2011; Ernest, 1989; Markovits & Forgasz, 2017; Moyer, Robison, & Cai, 2018; Young-Loveridge, Taylor, Sharma, & Hawera, 2006). Ernest (1989) proposed three broad views of mathematics. Firstly, an instrumentalist view in which mathematics is a set of unrelated facts, rules and skills. Secondly, a Platonist view where mathematics is a static but unified body of knowledge. Thirdly, a problem-solving view where mathematics is dynamic, an expanding and developing field of human creation and invention. It is empowering when mathematics is perceived as problem-solving because it implies that learners are expected to make sense of the world in mathematically meaningful ways (Schoenfeld, 1992).

Within a New Zealand context, Young-Loveridge et al. (2006) explored student perceptions of mathematics and found that most commonly students had a content-focused perception of mathematics mainly related to number and computation. Another common theme in student responses indicated a utilitarian view of mathematics; however, the researchers reported that few student responses were linked to a problem-solving view. A more recent study by Moyer et al. (2018) focused on high school students who had been taught using different types of mathematics curricula in middle school, reform or traditional. The researchers categorised responses related to students' view of mathematics as relational or instrumental. A relational view encompassed those responses which suggested that mathematics was related to problem-solving as well as understanding why it works, usefulness and relation to everyday life. An instrumental view implied mathematics was simply rules and procedures without any need for purpose, justification or utility. The researchers found that only a small group of students had a relational view of mathematics and predominantly students had an instrumental view of mathematics. There was no significant

Fig. 10.1 Initial word cloud frequency chart



difference in the view of students who had been taught using a reform or traditional curricula.

Similar to the studies described above, in the initial phase at the beginning of the DMIC intervention, most students gave responses (Fig. 10.1) in the questionnaire that mirrored Ernest's (1989) description of instrumental views of mathematics.

Comparable to the results of Young-Loveridge et al. (2006), half of the student responses (51%) indicated their belief that mathematics was synonymous with number and calculations and solely referenced number, times-tables or operations (addition, subtraction, multiplication, division). A small group of students (4%) also included other mathematical topics (e.g. measurement or geometry). Other student responses (28%) included problem-solving within their explanation. However, these responses were viewed as largely reflecting an instrumental view as this was typically amongst a list of words associated with number with no further explanation. For example, one student wrote: 'times-tables, dividing, plus, take-away, problem-solving, equals'. Finally, a small group of student responses (8%) had some alignment with Ernest's (1989) categorisation of a problem-solving view of mathematics with inclusion of the description of mathematics as thinking (8%).

We note significantly different student responses after a year of being in classrooms where the DMIC intervention had begun. Twenty-eight percent of student responses in the questionnaire still indicated instrumental views (Ernest, 1989) with responses only referencing number or calculations; however, the majority of students offered additional descriptions of mathematics (Fig. 10.2).

Interestingly, many student responses (54%) now aligned with Ernest's (1989) category of a problem-solving view or Moyer et al.'s (2018) description of relational views of mathematics. Within these responses, a frequent reference was learning mathematics as a type of participatory practices of working together, sharing ideas and asking questions. For example, one student wrote:

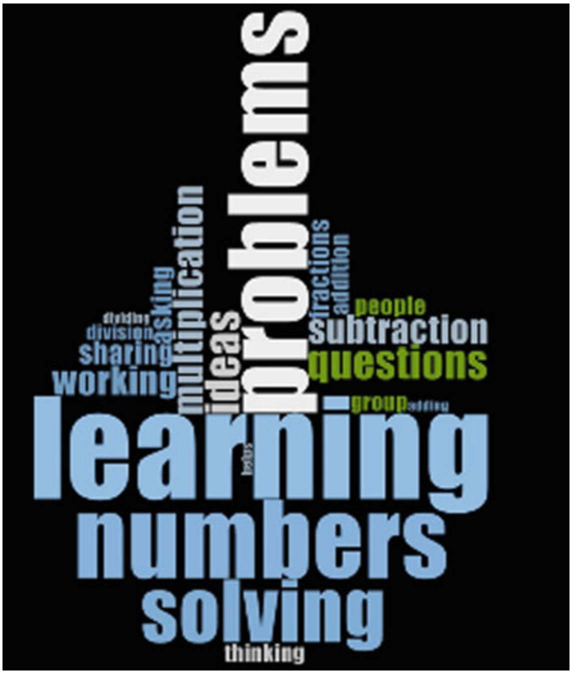


Fig. 10.2 Final word cloud frequency chart

> Solving of problems, friendly arguing, sharing lots of ideas and your smart thinking, working as a team/family together, participating and contributing, learning ratios, fractions, division, adding, multiplication, subtraction, decimal numbers.

Other student responses described mathematics as a way of learning and developing: ‘maths is another way to learn, it’s like a language with numbers that I think everyone should know’. Alternatively, other students described mathematics with reference to current and future utility: ‘an activity that can led you to your future education and job’. There was also a shift within the responses that reflected the cultural metaphors that the teachers were drawing upon in the classroom: ‘learning maths is being in a waka (canoe) with your whole group’.

10.4 Student Perspectives on the Nature of Mathematical Learning

Similar to investigating student beliefs about mathematics, other studies (e.g. Hodge, 2008; Hunter & Anthony, 2011; Moyer et al., 2018; Pratt, 2006) report on student perceptions’ in relation to their role in the mathematics classroom or how to succeed in mathematics. For example, Hodge (2008) examined younger students’ perceptions in regards to their role in the mathematics classroom. The researcher interviewed students after they had spent the first year in a classroom with reform-based instruction methods and then again after they had moved to more traditional orientated instruction in the second year. The students gave markedly different responses in regards to what it meant to be a good mathematics student in each class. In the first year, students overwhelmingly described mathematical competence as thinking about mathematical ideas and communicating these to others. In the second year, most students described competence as following the teacher's direction to solve a problem, remembering procedures and being patient. Similarly, Moyer et al. (2018) found that students who had experienced a traditional curriculum in middle school showed a stronger preference for individual work and reliance on the teacher. In contrast, students taught using a reform curricula were more willing to rely on themselves and other students than the teacher did. Another study by Pratt (2006) with UK students found that they viewed learning as an individual process and privileged listening over talking as a form of meaning-making in the mathematics classroom.

At the beginning of the DMIC intervention, these Pāsifika learners put a strong emphasis on passive listening as a means of mathematical learning or competence in the classroom. These interview responses aligned with the findings of Pratt (2006) and also reflect the cultural background of the students where silently listening is seen as a sign of respect (Hunter & Anthony, 2011). For example, the most common response (20%) that students attributed to making someone good at maths was passive listening. This included both listening to the teacher and to their peers: 'listen to my teacher, listen to other people if they're sharing'. Only one student provided a response that indicated they viewed listening for understanding as important: 'listening and asking questions'. Similarly, when asked what helps someone improve in mathematics, students again commonly emphasised (18%) the importance of listening to both peers and the teacher. Mirroring the previous responses, most of the statements implied a passive listening role with only one response indicating listening for understanding.

Interestingly, some students (22%) noted the importance of collaboration and participatory practices when referring to what made someone good at mathematics. For example, some responses noted the importance of sharing mathematical ideas and explanations. However, these were generally short responses that did not detail why or how this made someone good at maths: 'telling people, helping, sharing, explaining'. Other student responses drew on the notions of collectivism and family which are specific values important to Pāsifika people noted in a Ministry of Education document, the Pāsifika Education Plan (PEP) (2013). For example, students specified that working productively with others made someone good at maths: 'working together, being as a family'. Additionally, a group of students (18%) also explained their belief that to improve in mathematics you need to ask questions.

Although a number of students drew on collaborative frames, other students gave responses that indicated an individualistic view of improvement in mathematics. These students (14%) noted their beliefs about the importance of study and practice at home: 'practice at home my times-tables'. A small number of other student responses in relation to being good at mathematics or improving at mathematics noted aspects related to disposition including effort and willingness to take a risk.

Contrasting the earlier student responses, at the end of the year, in the interviews there was a greater emphasis (23%) on sharing mathematical ideas and explaining their thinking. Interestingly, the responses indicated a responsibility on the behalf of the person explaining to ensure others understood: ‘making sure everyone understands what you are saying and doing’. Similarly, another student stated: ‘sharing ideas and ask if they have got any questions’. These responses focusing on the importance of communicating with others in mathematics paralleled the work of Hodge (2008) who also noted an association of competence with communication after reform teaching had been established. Students continued to privilege listening as making someone good at maths (20%) and again this largely indicated a passive view; however at this point, three students provided responses that indicated listening for understanding. A larger number of student responses (18%) emphasised being able to work collaboratively.

In the final interviews, three new themes were noted with two of these related to mathematical dispositions. A number of student responses (14%) referred to effort: ‘if you put in this much effort (indicates wide with hands), you get this much in return (indicates wider)’. Also related to disposition, student responses (9%) noted that someone good at mathematics was willing to take a risk, make mistakes and keep persevering with confidence: ‘someone who is focused, has made mistakes, confident, shy a little bit, a person who can stand up to what they think. Anyone can be good at maths, you just have to believe’. Finally, a group of student responses (7%) noted mathematical practices as components of being good at maths: ‘challenging them [peers] and asking questions’ or: ‘we need to respect each other even if we disagree with an idea, we can’t say it in a bad way’.

A notable change in the final interviews were the increasing range of descriptions and attributes in the student responses that related to how an individual could get better at maths. The number of student responses that valued listening to improve in maths increased slightly (23%), with this increase related to an increased number of students indicating listening for understanding: ‘listen to other people doing their strategy so I can use their strategy to help with my learning’. The number of student responses that indicated passive listening remained the same. Other student responses (20%) identified providing explanations and revoicing their peers’ explanations as a means of getting better at maths. For example, one student response was: ‘explaining my ideas to my group, each and every detail so they can all understand’. Another common student response (14%) noted the importance of effort: ‘try really hard and give it what I’ve got’. In the final interview, a much smaller number of student responses identified asking questions (7%) or practice at home (7%).

10.5 Student Perceptions of Engaging and Participating in Mathematical Practices

It appears that there have been few studies that explicitly examine the views and perspectives of diverse learners towards engaging and participating in mathematical practices. Previous studies (e.g. Brown & Reeves, 2009; Hunter & Anthony, 2011; Sharma, Young-Loveridge, Taylor, & Hawera, 2011)) often provide a view of student perceptions of a specific practice, rather than perceptions of engaging in the practice. Additionally, most of the studies offer a snapshot in time rather than a focus on how student perspectives may shift over time. For example, Brown and Reeves (2009) investigated the views of students after participating in collective argumentation. This included asking students to recall experiences with collective argumentation and their perspective on whether collective argumentation should be used in other classrooms. Most students supported collective argumentation being used as a way for students in classrooms to take an active role in their own learning. In a New Zealand based study, Sharma et al. (2011) interviewed Pāsifika students about their perceptions of the importance of providing mathematical explanations. They found that the students largely positioned the importance of providing a mathematical explanation in relation to helping others. A small group noted the importance in relation to proving your own understanding and therefore demonstrating that you were not 'cheating'.

Another study by Hunter and Anthony (2011) used Pāsifika students' voice to examine from their perspective how they perceived their relationship as users and doers of mathematics. The students participated in an initial interview and then in ongoing interviews following mathematics lessons throughout the school year. The researchers found that early in the study, the students were reluctant to provide mathematical explanations both due to a lack of confidence but also because of the risk to their status when explaining in front of their peers. Students recognised the importance of asking questions but indicated difficulty in constructing appropriate questions. In the middle of the year, students displayed growing confidence in speaking and explaining their mathematical reasoning and had begun to view this as an obligation related to being part of the classroom community. Likewise, there was an increase in both competence and confidence to ask questions. At this point, students also began to display awareness of the role of mathematical argumentation; however, this still was not a readily accepted practice and caused a potential loss of confidence. In contrast, at the end of the year, students had transitioned to being able to confidently explain their reasoning, question peers and engage in mathematical argumentation. Hunter and Anthony (2011) noted that a key aspect in the change process was the awareness of the relational aspects to be considered when asking students to participate in mathematical practices.

The following section of the chapter focuses on student perceptions of providing mathematical explanations, questioning peers and disagreeing with mathematical ideas. An initial interview question asked students about their perceptions of the importance of providing mathematical explanations. Most commonly, student responses (23%) described giving an explanation as a way of helping their peers.

For example, one student said: ‘so it can help other learners who are stuck’. This was a similar result to Sharma et al. (2011) who found that Pāsifika students largely viewed explanations as a form of help for others. Also common in student responses (20%) was descriptions of providing mathematical explanations as a way to show their peers how they solved the problem: ‘so others know your ideas and how you solved it’. This was also similar to the findings of Sharma et al. (2011); however, a key difference here was that students in the earlier study related this to proving that you had not cheated, which was not evident in the current study. A smaller group of student responses (9%) considered that providing a mathematical explanation provided an opportunity to show a new way or to demonstrate a different strategy: ‘so everyone knows that we figured out the answer a different way’, a common focus in classrooms with norms related to the New Zealand numeracy project (Ministry of Education, 2004). In these initial interviews, a minority of student responses (9%) framed provided an explanation as beneficial for mathematical learning. These students described how providing an explanation was a way for them to make sense of the solution strategy to the task. For example, in one small group interview, a student began by saying: ‘to know your maths’, following this, her peer added on: ‘to know what you’re talking about and what you’ve done to get the answer’.

Student responses provided a range of reasons why they viewed mathematical explanations as important. However, a group of student responses (9%) referred to negative emotional reactions to being asked to provide a mathematical explanation. Most commonly, this was due to the potential of a possible negative reaction from peers: ‘other people might say ‘no that’s wrong’ and it freaks me out because it feels like I’ve done everything wrong’. Other students described feelings of being nervous or shy or fearing that peers would laugh at them.

Evident in this initial phase of the study was that the practice of asking questioning related to mathematics was not well established in the classrooms or a practice that these Pāsifika students found comfortable. When asked during the interview about how they felt about asking questions, only 12 of the students responded. Of these, 58% of the responses positioned questioning as a negative action or something that the students did not do because they felt shy or scared. Other students gave responses that indicated they felt uncomfortable with potentially losing face or making their peers lose face. This is highlighted in the excerpt below:

> Interviewer: How do you feel about asking questions?
>
> Elizabeth: No, because they’ll say “what?”
>
> Poinsettia: Hard, they might not get it
>
> Elizabeth: And you don’t want to explain again.
>
> Destiny: Yeah, it’s embarrassing.

This was also interesting given that as highlighted in Sect. 10.4, 18% of student responses in the questionnaires identified asking questions as a way of improving in mathematics. Another student response viewed questioning as acceptable because ‘we know everybody’, while 42% of the students felt confident about questioning because it was a way of challenging others to think while still being able to support them: ‘ask different questions and challenge them and if they don’t understand I can just explain it to them’. The teachers’ role in supporting questioning as a time for reflection upon a solution strategy was also evident: ‘The teacher will give us time when we need to ask questions and that’s the time when we can explain what we think about their strategy’.

Another interview focus was the perceptions of students towards engaging in mathematical argumentation during lessons. Specifically, students were asked to provide a reflection on how they felt about disagreeing with mathematical ideas. Many students (43%) responded to this question by describing the actions that they took during a lesson to indicate disagreement. Interestingly, these were often framed in a polite, non-confrontational way of disagreeing. This demonstrates how a mathematical practice which may be uncomfortable for students from a specific cultural background, such as these Pāsifika students, can be appropriated in a way that aligns with cultural values. For example, a number of students discussed how they would use questioning to indicate disagreement without directly stating their disagreement: we just say, ‘where did you get those numbers from and why did you use those?’. One student explicitly described why this was done: ‘we don’t really tell them they’re wrong, we just ask them questions so they realise themselves and it’s less harsh’. Other students described how at this point in the year, their teacher mediated the process of agreeing or disagreeing: ‘the teacher say, “do you agree?” to us and we just say “no” or “yes”’. Seven of these students also indicated the need to provide a reason for disagreement with the teacher again taking a key role in facilitating the need for reasoned disagreement: ‘we say we disagree with your answer and then my teacher says, “why do you disagree?” and then we have to explain’. Only one of the students provided a reason which indicated a view that disagreement was linked to learning. In this case, they viewed disagreeing as beneficial for other students: ‘it’ll be helping their learning’.

A significant group of students (20%) indicated discomfort with engaging in mathematical argumentation. Some of these students simply stated that disagreeing was something that they did not personally do within mathematics lessons. Most commonly, four students described feelings of nervousness when engaging in disagreement. This was often related to individual feelings of concern that they may disagree and be incorrect: ‘I get nervous because they might be right’. Another student expressed concern that she would upset others if she disagreed with them. Finally, a pair of students shared an experience in the classroom where they described the difficulty of trying to articulate an argument.

> Sefina (referring to her interview partner): John, he actually disagreed so he shared his idea until he was asking her questions and she couldn’t answer back.
>
> Teuila: It was challenging for me.
>
> Sefina: It was actually challenging, disagreements are actually really hard.
>
> Teuila: Because when they ask you the questions, it is really hard to explain it, you can’t put it into words.

Student responses in these initial interviews show the sustained time required to shift practices in the classroom and introduce new roles for students. They highlight the difficulty in changing students' perceptions of their role within the mathematics lesson. While the teachers were encouraging the students to enact mathematical practices, engaging in these were often emotionally charged experiences for the students. The student responses are similar to those reported by Hunter and Anthony (2011) with many students referencing a lack of confidence and feelings of nervousness related to status. Responses from the students also reinforce the need described by Hunter and Anthony to consider relational aspects when asking students to engage in mathematical practices. The teachers took a key role in supporting students to engage in the practices and facilitating these within the lessons. However, the students also take an important role in choosing whether to follow the new practices or to resist and it is interesting to note how students were able to enact the practices while still adhering to their cultural values such as respect and collectivism (Ministry of Education, 2013).

The final student interviews provide a window into the shifts in the classroom and the changing student perceptions of their roles. While students initially most commonly viewed the purpose of giving an explanation as helping their peers, at the end of the year, they now most commonly described (25%) mathematical explanations as a form of justifying their thinking. For example, a student described that it was important to explain: 'to show people how you got your answer but not only the answer but how you worked it out and what strategies you've used that helped you'. Student responses (18%) continued to describe mathematical explanations as a way to show their peers how they solved the problem and a smaller number of responses (14%) referenced the importance of an explanation as helping peers. In these final interviews, some student responses (11%) began to reflect on how mathematical explanations were a form of collaboration helping both their own learning and the learning of their peers. For example, a student described how their teacher had asked them to explain their understanding of probability to another student: 'then I began to understand it and I just felt that buzz'. Another student described the collaborative learning opportunities facilitated by explanations during large group discussions: 'When we have ideas, another group goes before us and they show their idea, and say that if we hadn't finished, another group comes and explains their ideas, which gives us more ideas. It's better when we share our ideas together because we get more ideas'. Interestingly, no students shared negative reactions to giving a mathematical explanation in the final interview.

Students noted the shifts in both their own and their peers' confidence to ask questions over the year. For example, two students reflected:

> Tomaso: I've made a big difference from the start of the year, I didn't ask any questions.
>
> Josiah: Yeah we were quiet.
>
> Tomaso: Yeah I'd just sit there.

A number of the students (18%) referred to the actions that their teacher had taken to encourage them to ask questions: 'She says "always ask questions when you don't understand" and to take risks in what you're learning'. These teacher actions were ongoing as the teacher pressed the students to develop a sense of personal responsibility to question for understanding. For example, a pair of students described:

> Hamuera: If we don't ask questions, then she'll (the teacher) ask us to explain and if we can't then…
>
> Wiremu: She'll say we weren't doing our job.

In explaining when and why, they would ask questions during a mathematics lesson, student responses (18%) referred to asking questions when they were stuck or lacked understanding. One student also noted that they asked questions as a way of helping their peers.

Most commonly, student responses (23%) at the end of the year described themselves as confident to ask questions, although two of these responses described being both confident and nervous. The growing confidence of the students appeared to be related to two key factors. Firstly, teacher actions which positioned questioning as a non-threatening action was not related to status. For example, one student described: 'People don't judge, they just ask questions like why we chose this?'. A second key factor appeared to be the relationships within the classroom between the students along with the growing familiarity of the practice: 'They're my friends and I'm not shy to ask it because I already know those people and I know how to explain, I've done it for a long time'. In these final interviews, there was a significant decrease in student responses which associated negative emotions or experiences with asking questions. A group of students (11%) described themselves as shy in the context of questioning; however these were generally in the context of a personal characteristic, for example: 'I'm shy'. Only one of these responses related to the potential of embarrassment or loss of status.

Shifts were noticeable in relation to student perspectives of disagreement and mathematical argumentation. Most commonly, students (59%) now described the need for providing reasoned disagreement: 'If we think it's wrong then we'll disagree, we just say 'I disagree' and explain why'. Students provided a range of explanations for why they thought they should provide reasons for their disagreement. Of these students, 27% viewed reasoned disagreement as a way to help their peers learn or to correct their thinking: 'It's important to explain why because they might have got their calculations wrong'. Other students (15%) stated that it was important to give reasons for disagreement so that peers would know why they were disagreeing. A smaller group of students (12%) viewed reasoned disagreement as a way to help everyone learn: 'That gives us all a challenge into what we are doing, and that helps us learn in class'. Similar to the other mathematical practices of giving explanations and asking questions, there was a significant reduction in students sharing negative reactions to this practice. In the final interview, only one student provided a negative reaction stating: 'It's a bit hard because sometimes I don't get it'.

10.6 Conclusion

This chapter draws on the voices of diverse students to examine the changes in their perspectives over a school year with the introduction of a strength-based approach focused on ambitious mathematics teaching. It provides an exemplar of how students can develop a strong mathematical disposition while maintaining their cultural identity. Data from the student responses to the initial questionnaires highlights that many students began with a narrow conception of mathematics that mirrored procedural teaching focused on number and computation. This view aligned with Ernest's (1989) description of an instrumentalist view whereby mathematics is seen as sets of unrelated facts, skills and rules rather than a sense-making activity. Similarly, students viewed their role within the mathematics classroom as largely a passive position in which they listened to the teacher or their peers in order to learn. The continuing prevalence for some students of narrow, instrumentalist descriptions of mathematics at the end of the first year of the intervention demonstrate the long process of shifting student perceptions and views of mathematics.

After one year of participating in an inquiry community, students (mostly of Pāsifika descent) began to shift their perceptions of the nature of mathematics from instrumentalist to problem-solving or relational understanding. Students' perspectives on learning mathematics shifted from passive listening to sharing ideas and explaining thinking to help others understand. Students' perceptions of engaging in the mathematical practices shifted from explaining to inform others to asking questions and disagreeing with peers to help own and others' learning. These findings respond to Civil's (2016) international call to use a strength-based approach in STEM education, especially in non-dominant communities.

Overall, the shifts in student descriptions of mathematics and competence in mathematics highlight the impact of the change in teacher pedagogy and practice in the mathematics lessons. Specifically, it shows the potential for change in diverse student perceptions of mathematics to a more inclusive and participatory model of mathematics. Clear examples are provided of how students shifted to privileging communicating mathematical thinking and reasoning as evidence of competence within a frame of mutual responsibility.

Evident throughout the analysis of the student voice was the impact of the students' cultural background, values and beliefs in relationship to the changes taking place in the classroom. Initially, students did not link mathematics as a subject to their cultural background, perhaps indicating a view of mathematics being 'culture-free'. Despite this, students consistently drew on cultural values such as outlined in the PEP (Ministry of Education, 2013) when reflecting upon competence or appropriate ways to learn. Mathematical practices were carefully introduced by the teachers with a focus on culturally responsive and sustaining pedagogy. However, a significant number of student responses indicated an initial dissonance between the students' perceptions of appropriate and comfortable behaviour and the newly introduced practices. In contrast, other students were able to engage in these mathematical practices in a way that both honoured and maintained their cultural values.

At the end of the first year intervention, we can see a significant shift in how students viewed their role in the classroom along with the role of mathematical explanations, questioning and mathematical argumentation. Justification had become a key feature of the classroom with students noting the need for reasoned explanations both to benefit their own and others' learning. The chapter adds to research literature focused on mathematical practices and makes a contribution in examining diverse student perspectives on engaging in these practices. For the students involved in this study, the strength-based approach which drew on culturally responsive and sustaining pedagogy enabled them both to develop a strong mathematical disposition whilst also maintaining their cultural identity.

Appendix

Interview questions:

1. Tell me about yourself as a maths student.
2. Tell me about what learning maths is like in your class.
3. What sorts of things do you do to help you learn maths?
4. What does your teacher do to help you learn maths?
5. What do you do if you get stuck?
6. Do you work with others or mostly by yourself?
7. Do you like maths?
8. What are your favourite parts of the maths lesson/why?
9. Can you tell me about a time when you've felt really good in maths?
10. Are there parts of maths that you don't really like—tell me about them.
11. In your maths lesson how does it feel to be a …? Explain.
12. Is it important for you to be able to explain how you solved a problem? Why?
13. Is it important for you to understand how other students solved a problem? Why?
14. How do you feel about disagreeing with people?
15. How do you feel about asking someone a question in maths?
16. What makes someone good at maths?
17. What would you need to do to get better at maths?

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Chapter 11
Affect and Engagement in STEM Education

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Abstract The current interest and focus on STEM education is largely a response to affective issues related to participation and engagement in mathematics and science. Concerns about low levels of interest and engagement are key factors in students opting out of these subjects, attaining low levels of achievement leading to declining enrolments and concerns about shortages in people taking up STEM-focused careers. This has created a sense of urgency and stakeholders have seen STEM education as a way to ameliorate these issues and concerns. However, the issues are, at least partially, fundamentally affective in nature, and so the response of educators to the current crisis must also be 'affective'. In this chapter, we examine the philosophical and theoretical foundations of current STEM education approaches, and then interrogate current research relating to STEM education, with a particular focus on Australia, to examine whether affective issues are central in current STEM initiatives.

11.1 Introduction

STEM education has been identified as a path to address a global need for contemporary societies to transform, innovate, adjust and adapt (Lowrie, Downes, & Leonard, 2017). In education, STEM has also been viewed as a response to affective issues relating to participation, interest and engagement in the individual disciplines of mathematics and science (Becker & Park, 2011; National Research Council, 2014). In 2005 a recommendation was handed down by the OECD that governments take

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action to address the decline in students studying science, technology, engineering and mathematics (STEM) due to declining participation rates (OECD, 2006). Well over a decade later the global STEM agenda continues to build momentum yet there is evidence that during the past ten years the proportion of upper secondary and tertiary level students studying in STEM fields has continued to decline (Hughes, Luo, Kwok, & Loyd, 2008; Roberts, 2013; Wang & Degol, 2014). Over the past two decades participation rates in senior secondary science and mathematics, in particular, have declined in Australian schools and internationally (Kennedy, Lyons, & Quinn, 2014), having a direct impact on students entering STEM-related fields.

In the Australian context, Kennedy et al. claim that although the scale of declining enrolments is unclear, government and industry bodies are concerned and feel these declines must be addressed. These continuing declines in enrolments and participation imply that current policy and programs relating to STEM in schools are not delivering the desired outcomes and affective issues appear to continue to remain a significant influence.

In this chapter we explore the current STEM context, focusing on affect in STEM. We interrogate policy and existing programs to determine whether student affect is considered and addressed within STEM programs. We also propose that one of the underlying factors contributing to the challenges of STEM programs is the lack of attention given to improving affect and consequently achievement in the individual disciplines of mathematics and science. First, we briefly draw on literature to establish a definition of STEM for this chapter. We then provide clarification of 'affect' in relation to STEM and our discussions. This is followed by a discussion of student engagement and the challenges experienced in promoting positive engagement with mathematics and science. Finally, we explore STEM policies and programs to examine whether affective issues are central in current STEM education initiatives.

11.2 Defining STEM Education

It is challenging to find a common definition of STEM as it pertains to education. English (2017) refers to the myriad of viewpoints and the contentious nature of STEM with regard to the often unequal attention given to the four disciplines (Lowrie, Downes et al., 2017; National Research Council, 2014). A definition from Shaughnessy (2013) highlights the mathematics and science embedded within STEM: "STEM education refers to solving problems that draw on concepts and procedures from mathematics and science while incorporating the team work and design methodology of engineering and using appropriate technology" (p. 324). Although there are debates regarding the inclusion of other disciplines such as the arts, for the purpose of this chapter we draw on Shaughnessy's definition.

Just as it is difficult to find a common definition of STEM, it is similarly challenging to find a consistency amongst exemplars of STEM practice in schools. This is perhaps due to the fact that STEM research is an emerging field and there is no specific STEM curriculum in Australia nor a specific engineering curriculum.

According to Siekmann (2016), STEM education and training seeks to establish relationships between the four disciplines for the purpose of improving scientific and technical skills via an emphasis on critical and creative thinking. Lowrie, Logan, and Larkin (2017) provide a synopsis of the current approaches to STEM practices ranging from a treatment as individual discipline areas to a more common integration or fusion of all or some of the four disciplines with a focus on contextualised real-world experiences.

The integrated approach to STEM is noted to have several advantages, including the potential to improve affective elements such as interest and motivation. However, a meta-analysis of STEM-related research by Becker and Park (2011) failed to reveal studies that measured the influence of integrated STEM education on affect. A more recent analysis of research into the integrated STEM approach (National Research Council, 2014) revealed some evidence of improved academic achievement and indicated that integrated STEM programs or interventions such as school-based projects and curriculum units can support the development and maintenance of interest and identity in STEM, yet more research is required. It is believed that a disadvantage of the integrated STEM approach is that the individual disciplines of mathematics and engineering are often neglected due to an increased focus on technology (Lowrie, Logan et al., 2017; National Research Council, 2014).

Lowrie, Logan et al. (2017) cite further disadvantages to the integrated STEM approach including time limitations for teachers to master a different pedagogical approach, challenges in separating content knowledge and assessment, and issues in addressing learning outcomes. Lowrie, Logan et al. (2017) propose a shift away from focusing on content knowledge to a focus on STEM practices that encompass ideas, methods and values. This shift away from a focus on content knowledge may be one way of addressing affective issues in STEM:

> It is concerned with how forms of understanding are connected to individual and collective self-expression, how modes of action are connected to individual and collective self-development, and how ways of relating to one another are connected to individual and collective empowerment and self-determination. (p. 26)

While there may be an alternative approach to STEM education as proposed by Lowrie, Logan et al. (2017) we cannot address affective issues without a clear understanding of what they entail. The following is a brief outline of the affective domain and its relation to STEM education.

11.3 Affect and STEM

The affective domain has been a long-standing educational concern, particularly in subjects like mathematics and science that have historically been seen as *emotionally difficult* for some. Although there have been studies looking at affective aspects of education for over 70 years, it perhaps became more prominent in the 1980 s with particular concerns about the participation of girls in STEM subjects (e.g. in mathematics, Vale & Leder, 2004). At this time it became important to consider not only the cognitive and psychomotor learning of students but also the affective dimension of their learning.

However, over the years what constitutes the affective domain has been unclear and variously defined (Grootenboer & Marshman, 2017), and this has led to a lack of clarity about some of the related research and educational development. A seminal understanding of the affective domain was outlined by Krathwohl, Bloom, and Masia (1964), alongside the widely known Bloom's taxonomy (Bloom & Krathwohl, 1956). The affective domain of Krathwohl, Bloom, and Masia (1964) included aspects that focused on attitudes, awareness, attention, concern, interest and responsibility. Later, a range of other models and conceptualisations were developed that tried to delineate what was 'affective', and how the various affective aspects related to one another. One was developed by Grootenboer (2003) who included beliefs, values, attitudes and emotions (see Fig. 11.1)

In this understanding of the affective domain, beliefs are seen as more *cognitive*, and less temporal than emotions. Of course, there are others who have defined the affective domain differently, for example, some including *beliefs* and/or *values* (e.g., McLeod, 1992) and others not, while others have included aspects like *identity* (e.g., Lerman, 2009). Furthermore, while the initial work in this area was primarily undertaken within a psychological tradition, affect has now been considered in a broad range of academic traditions including sociology (e.g., Lerman, 2009) and psychotherapy (e.g., Brown, Brown, & Biddy, 2008). Thus, the affective domain, and how it relates to education, is a murky topic, particularly due to the lack of clarity about what *affect* is, and both how it is learned and how it impacts learning, in STEM.

There is no scope here to provide a deep and robust outline of the affective domain, but we will now briefly outline how it will be defined and what will be included, as we consider affect in relation to STEM education. In the end, we are not so much

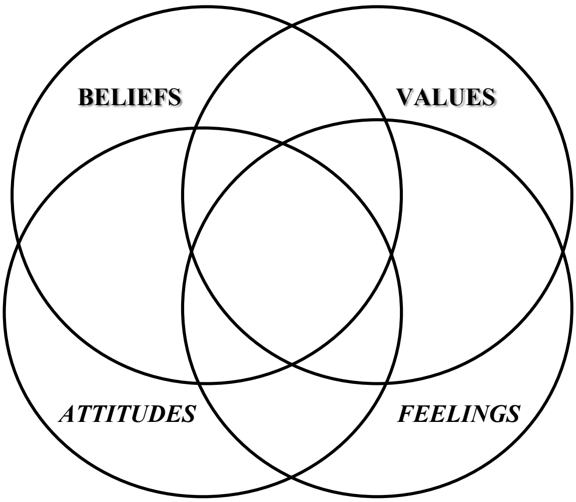

Fig. 11.1 The affective domain (Grootenboer, 2003)

concerned about providing a definitive conceptualisation of affect, but rather how the various aspects work holistically to impact learning in STEM, and how these can lead to greater student engagement.

Beliefs, as defined by Philipp (2007) are “psychologically held understandings, premises, or propositions about the world that are thought to be true” (p. 259), and as such beliefs impact how an individual sees the world and responds to it. In terms of STEM education, beliefs therefore filter new experiences and information, and in this way they can moderate the content and the processes of student learning. Historically, some of the individual STEM disciplines have been hampered by beliefs that are not necessarily representative of the world (i.e. accurate) and/or helpful for students learning in that discipline, and perhaps the newness and novelty of STEM can ameliorate some of these traditional belief-based barriers.

Attitudes are less ‘cognitive’ than beliefs, and more ‘emotive’, and are seen to develop as either positive or negative response to repeated experiences. Thus, attitudes are relatively stable, and they act as “predispositions to action which invoke preferential responses to the event or object concerned” (Grootenboer & Marshman, 2017, p. 19). As with beliefs, attitudes—both positive and negative, are seen to both influence learning and engagement, and to be the outcome of school experiences.

Emotions and Feelings are temporal unstable affective responses to a particular situation, event or experience, and can include a wide range including excitement, fear, joy, panic, boredom and frustration. Again, students will experience emotions as an integral part of learning, and these can impact students’ engagement in their learning, and their developing beliefs and attitudes towards STEM and learning in STEM.

Interest is also a common affective quality that is focused upon in the science and STEM literature, and includes to a greater or lesser degree the aspects noted above. Interest is multifaceted and is seen as a forerunner to engagement and participation (Christidou, 2011) There are other components of the affective domain including confidence, self-esteem, self-efficacy, dispositions and fun, and some even include notions of *identity* in discussions of affect in education. These are all inter-related, and together all these affective qualities/responses are the outcome of STEM learning and engagement, but also impact STEM learning and engagement.

11.4 Student Engagement

The construct of engagement is one that is often misunderstood and underestimated in education, yet is one of the driving forces behind the current STEM agenda in schools. Although the term is used frequently by researchers and teachers alike, it is often simply perceived as students who being compliant, on task, and well behaved. However, the construct is more complex and represents a much deeper relationship with work and learning, with serious implications for what we teach and how we teach it. For the purpose of this chapter, we present a definition of engagement and some clarification of the reciprocal relationship between engagement and motivation.

Although there are a variety of definitions for engagement, it is typically defined as a combination of behaviour, affect and cognition (Fredricks, Blumenfeld, & Paris, 2004). Behavioural engagement (sometimes referred to as operative engagement) encompasses the idea of active participation and involvement. Cognitive engagement relates to the idea of investment and recognition of the value of learning, and affective engagement encompasses students' reactions to school, including teachers and peers. Viewed in this multi-dimensional way, engagement can be defined as the coming together of the three facets: behavioural, affective and cognitive (Fair Go Team NSW Department of Education and Training, 2006), leading to students enjoying, valuing and making connections with STEM concepts both within and beyond the classroom. Arguably, if students are more deeply engaged in STEM during the school years, academic achievement should improve, leading to more students taking up further study in STEM-related fields and addressing the national agenda of improving Australia's capacity to be competitive in the global market.

The terms engagement and motivation are often closely associated, yet although both are driven by cognition, the constructs are very different (Fredricks et al., 2004; Ryan, 2000). Engagement signifies the actions and behaviours that are a result of motivation: that is, the individual's relationship with school, curriculum and pedagogy (Attard, 2013). When a student is engaged with learning, he or she has been influenced by motivation, yet on its own motivation is driven by one's beliefs and one's drive to engage and work effectively (Martin, 2008; Wang & Degol, 2014). The cognitions underpinning motivation can be encapsulated by two questions: "Can I do my schoolwork?" and "Do I want to do my schoolwork and why?" (Ryan, 2000), where the cognitions relating to engagement are projected outwards towards schoolwork, involving a student's investment and effort towards learning and the utilisation of specific learning strategies in order to achieve learning goals. Knowledge of student motivation can influence teachers and their expectations of students, the way their classes are structured and the way curriculum is delivered. When teachers adapt their practices to improve or maintain motivation, this in turn influences student engagement and achievement levels (Martin, 2005). STEM education potentially provides important opportunities for improving student motivation and engagement due to the hands-on and operative nature of the individual discipline areas. However, we are concerned that existing school disengagement within the disciplines of mathematics and science may hinder the intent of STEM initiatives if they are not addressed.

11.5 Engagement with Mathematics, Science and STEM

Arguably the foundations of STEM are formed within the disciplines of mathematics and science, yet these are two key school subjects that continue to be a challenge in relation to developing and maintaining high levels of student engagement that result in students continuing their study beyond the compulsory years. Student engagement is considered a key contributing factor to academic success and continued study in mathematics and science (Barker, Dowson, & McInerney, 2005; Hughes et al., 2008;

Maltese & Tai, 2010; Wang & Degol, 2014). If educators expect students to develop substantive engagement and achieve academic success in STEM, we argue that issues of engagement in mathematics and science must first be identified and addressed to ensure the implementation of STEM initiatives delivers the intended results. Improved academic success in the disciplines of mathematics and science is critical if students are to successfully apply the knowledge and skills from the individual disciplines to STEM-related learning.

Issues in engagement with mathematics and science during the school years have long been of international concern (Attard, 2014; Everingham, Gyuris, & Connolly, 2017; Maltese & Tai, 2010). The middle years of schooling are specifically well documented in literature for being a critical time in the formulation of positive attitudes towards mathematics. It is a widely held belief that it is during this time that adolescents make the decision to withdraw from or continue the study of science or mathematics due to experiences that occur within the classroom (Australian Curriculum Board, 2009; Maltese & Tai, 2010). Of further concern is emerging evidence that disengagement and negative attitudes may form even earlier in students' lives (Commonwealth of Australia, 2008; Larkin & Jorgensen, 2015). This has created a sense of urgency in terms of addressing the causes of disengagement and perhaps provides sound justification for the implementation of STEM programs from the early years of schooling. Early implementation of STEM programs may prevent later disengagement with mathematics and science.

There are similarities amongst the issues and influences on student engagement in mathematics and science as documented by Kennedy et al. (2014) who claim there are 'blockers' in both disciplines when it comes to students enrolling in senior secondary mathematics and sciences courses: "self-perception of ability, perceptions of difficulty and usefulness, previous achievement, and interest and liking of mathematics" (p. 44). Arguably these 'blockers' may be linked to student affect and engagement in the early and middle years of schooling. Further extending this sentiment, Ainley and Ainley claim: "students bring to their learning a legacy of thoughts and feelings associated with earlier learning experiences and this history colours engagement" (2011, p. 4). Declines in engagement with mathematics and science are often attributed to similar factors. A lack of curriculum relevance, pedagogical practices that focus on content consumption, a lack of connection within and amongst mathematics topics or scientific disciplines and perceptions that mathematics and science are difficult and inaccessible are commonly listed as influences on student engagement (Boaler, 2009; Christidou, 2011; Maltese & Tai, 2010; Patrick, Ryan, & Kaplan, 2007; Simon & Osborne, 2010).

Research by Attard (2013) revealed the teacher as the core influence on engagement. This influence was articulated through the Framework for Engagement with Mathematics (FEM) (Attard, 2014) (Fig. 11.2) which details two separate yet interrelated elements of teacher practice that influence engagement: pedagogical relationships and pedagogical repertoires. Pedagogical relationships refer to the interpersonal teaching and learning relationships between teachers and students that optimize the learning of and engagement with mathematics. Pedagogical repertoires refer to the teaching practices that are employed by the teacher in day-to-day teaching. Although

Aspect	Code	Element
Pedagogical Relationships	In an engaging mathematics classroom, positive pedagogical relationships exist where these elements occur:	
	PK	Pre-existing Knowledge: students' backgrounds and pre-existing knowledge are acknowledged and contribute to the learning of others
	CI	Continuous Interaction: interaction amongst students and between teacher and students is continuous
	PCK	Pedagogical Content Knowledge: the teacher models enthusiasm and an enjoyment of mathematics and has a strong Pedagogical Content Knowledge
	TA	Teacher Awareness: the teacher is aware of each student's mathematical abilities and learning needs
	CF	Constructive Feedback: feedback to students is constructive, purposeful and timely
Pedagogical Repertoires	Pedagogical repertoires include the following aspects:	
	SC	Substantive Conversation: there is substantive conversation about mathematical concepts and their applications to life
	CT	Challenging Tasks: tasks are positive, provide opportunity for all students to achieve a level of success and are challenging for all
	PC	Provision of Choice: students are provided an element of choice
	ST	Student-centred Technology: Technology is embedded and used to enhance mathematical understanding through a student-centred approach to learning
	RT	Relevant Tasks: the relevance of the mathematics curriculum is explicitly linked to students' lives outside the classroom and empowers students with the capacity to transform and reform their lives
	VT	Variety of Tasks: mathematics lessons regularly include a variety of tasks that cater to the diverse needs of learners
Students are engaged with mathematics when: Mathematics is a subject they enjoy learning (affective) They value mathematics learning and see its relevance in their current and future lives, and They see connections between the mathematics learned at school and the mathematics used beyond the classroom		

Fig. 11.2 The framework for engagement with mathematics (FEM) (Attard, 2014)

the FEM is specific to mathematics, it is reasonable to conclude that these elements would also influence engagement with science. Similarities between the ideas, methods and values that comprise Lowrie, Logan et al.'s (2017) STEM Practices model and the FEM (Attard 2014), along with the hands-on and contextualised nature of integrated STEM tasks suggest that the development of pedagogical relationships along with appropriate STEM-related pedagogical repertoires could reasonably eventuate in cognitive, operative and affective engagement. However, such development would require significant teacher professional learning opportunities. Such opportunities are often reliant on policy to which we now turn, to explore how and if the affective domain is acknowledged and addressed.

11.6 STEM Policy: Addressing Affective Issues?

In describing STEM policy, we are referring to frameworks for STEM-specific objectives as reflected in legislation, policy or strategy statements (Marginson, Tytler, Freeman, & Roberts, 2013). The motivation around the need for STEM policy and the generation of a ‘pipeline’ of STEM education at both school and tertiary level concern the strengthening of the STEM labour force. An educational pathway for students in STEM fields is considered instrumental in promoting economic growth and well-being and responds to the major skill shortages in STEM-based industries (Marginson et al., 2013; Watters & Diezmann, 2013).

Globally there appears to be a range of objectives and approaches regarding STEM legislation and policy. These generally concern supporting increased achievement in STEM by promoting engagement and through content revision and pedagogy reform (Marginson et al., 2013). This is particularly emphasised at the primary and lower secondary level through intervention programs that claim to focus on engaging all students in mathematics and science in order to increase the intake of students into STEM-related subjects in higher education. This agenda is particularly targeted towards under-represented groups.

In generating curriculum reform, whether it be general or specifically related to science and mathematics, there are many competing choices to be considered (Marginson et al., 2013). In Asian countries, who are already demonstrating greater success in STEM programs, as illustrated in PISA results, there is a shift of focus from disciplinary knowledge to nurturing creativity, problem solving, collaboration and higher order thinking. Australia’s policy discourse is largely borrowed from Europe, the United States and other nations (Lowrie, Leonard, & Fitzgerald, 2018). Many western countries choose a focus on inquiry in science and problem-solving in mathematics, when choosing a STEM curriculum focus (Marginson et al., 2013). There appears to be a common theme globally on the purpose of STEM to promote student engagement, academic success, and preparedness for the workforce through inquiry and problem solving, Asian countries consistently outperform the rest of the world, and the gap continues to grow. This is usually credited to a culture that has maintained a high value for education, greater quality of teachers, employment of evidence-based practice, and a collective ‘push’ at a national level, and Asia’s success is likely one of the motives for Australia’s desire to improve international rankings and increase its global competitiveness.

Despite Australia’s shift to the promotion of engagement in STEM subjects through real-world settings, legislation is still yet to translate to practice. ‘Translation and impact’, as described by Lowrie et al., (2018) remain a challenge. That is, current research has largely failed to create knowledge that is usable, scalable and sustainable. This usable knowledge is widely recognised as a result of successful school-community partnerships whereby students gain industry knowledge and engage in educational experiences that value innovation and creativity (Office of the Queensland Chief Scientist, 2013; Watters & Diezmann, 2013). This is referred to as a process of ‘curriculum setting’ when referring to higher university programs being responsive to the occupations that STEM graduates are preparing to enter (Office of the Queensland Chief Scientist, 2013).

Further, the Australian Government has signified that within their vision of a successful STEM education system there must be a rise of the prestige and preparedness of teachers, both by upskilling pre-service and practising teachers and attracting high achievers in STEM to the profession. It is in the government's third suggestion that the clarity fades, suggesting we "think bold, collaborate and lead change" (Prinsley & Johnston, 2015, p. 1). Thus, a national approach to STEM education is discussed but not specified in the detail required for implementation. Many Australian Government documents released over the last decade support these suggestions documents (for example, Department of Education and Training, 2018; Office of the Queensland Chief Scientist, 2013; Prinsley & Johnston, 2015); however, there is little mandating or provision of specific guides regarding the implementation of these ideas in actual school settings outside of the specific mandatory Science and Mathematics State Syllabus documents. Although there is a National Curriculum for Technologies (Australian Curriculum and Reporting Authority, 2018), at a state level this content does not appear in its own document but is rather found in the state science syllabi. By teaching content and skills from each discipline separately, their real-life application is not demonstrated, instead hoping that students will see the connections (Timms, Moyle, Weldon, & Mitchell, 2018).

Given the emphasis placed on pedagogical reform in Australia, it is surprising that there has been no mandating of STEM specific professional development for teachers. For instance, a *National STEM School Education Strategy, 2016–2026* was introduced in 2015 by the Australian Education ministers (Education Council, 2015). The two main goals of this policy are to ensure that students finish school with strong foundation STEM skills and to inspire students to take on more challenging STEM subjects. One of the five strategies suggested to achieve these goals is to increase student STEM ability, engagement participation and aspiration. The policy describes this action as follows:

> Students' early interest in STEM is not translating to ongoing engagement and participation in STEM education. While evidence shows students have a natural interest in science, they don't necessarily understand the relevance of STEM education, particularly maths. Research shows that there is an interrelationship between student aspirations towards STEM careers and engagement in STEM subjects. Mathematical thinking is a fundamental skill that underpins all STEM learning. The sequential nature of mathematical learning means that students who fall off the 'maths pathway' early can struggle to achieve sufficient levels of mathematical literacy. (2015, p. 8)

This quote strengthens the argument we present in this chapter that affective issues in both mathematics and science need to be addressed in order for STEM initiatives to have lasting and sustainable impacts. As mentioned above, the suggested strategies from the Education Council are relevant and reflective of evidence-based practice; however, there are no practical suggestions or mandated changes within the classroom setting. The 'action' suggested in the report rather is to make subjects mandatory in secondary education and acknowledge the greater load of advanced STEM subjects through initiatives such as a university entrance bonus point scheme.

On a smaller scale, each Australian state and territory government have released policies that reference STEM in education. The commonalities of these policies include three priorities; student outcomes, teacher workforce and curriculum (Timms et al., 2018). In their *Challenges in STEM Learning in Australian Schools Literature and Policy Review,* Timms et al. highlight the alarming reality of the effect of STEM National strategy in Australia, despite these state and national efforts for reform. In addressing a 2003 report, *Australia's Teachers, Australia's Future*, which explores the advancement of innovation, science, technology and mathematics, a very grim reality is highlighted: "A great deal has been written on the importance of STEM to Australia's future. It is therefore concerning that a report written this long ago still accurately portrays the present state of affairs." (Timms et al., 2018, p. 9). Significantly here, these issues can be seen to be, at least partially, affective in nature.

11.7 STEM Programs in Australia: Addressing Affect?

There are a multitude of significant STEM initiatives being implemented in Australian schools, school systems, universities, within communities and the business domain to encourage STEM education. The Department of Education and Training (2018) online document, *Support for Science, Technology, Engineering and Mathematics (STEM)* lists a few of these government funded programmes that have been implemented to improve STEM education in Australia. Under the 'Inspiring STEM Literacy' measure of the 'National Innovation and Science Agenda', the government funds school-based programs such as 'Early Learning STEM initiatives', 'Let's Count', 'Little Scientists' and 'Early Learning STEM Research'. Similarly, the government funds programs to support teachers in implementing quality STEM education in schools. 'Science by Doing', 'Primary Connections: Linking Science with Literacy', 'ReSolve: Maths by Inquiry', 'Digital Technologies Hub' and 'Coding Across the Curriculum' are websites that provide comprehensive online resources and activities that are freely available to teachers that also aim to enhance their confidence and competence in STEM education (Sharma & Yarlagadda, 2018). The government furthermore funds a number of STEM education programs that take place outside of the school environment. 'Digit', which targets groups under-represented in STEM, and 'Curious Minds', which targets high-achieving female students, are ICT Summer Schools for students from Years 9 and 10. They involve a series of summer schools that give these targeted students a chance to participate in digital technologies and explore related careers.

The descriptions and proposed aims of several of these school-based programs appear to have some affective objectives. The Department of Education and Training (2018) document conveys that the aim of the 'Early Learning STEM Initiatives' program is to "promote *positive learning experiences* for children". Similarly, the same document suggests that it provides the opportunity for "families and children to take part in *fun* and *exciting* STEM activities" and that it will "*inspire* curiosity and *interest* in STEM among preschool-aged children". The program, 'Little

Scientists', was designed to help educators "lead *fun* inquiry-based learning activities" while the 'Little Scientists' website voices that "children need to be given the opportunity to explore the world in a nurturing and playful setting that boosts their *natural eagerness to learning*" (Little Scientists, 2019). The residential camp, 'Curious Minds' is described as a "mentoring program with the aim of *igniting girls' passion* and participation in STEM" (Department of Education and Training, 2018) while the 'Curious Minds' creators express their vision to "contribute to building Australian's scientific community through *inspiring* and developing our best science students" (Australian Science Innovations, 2019). The 'reSolve: Maths by Inquiry' program was designed to "help students learn mathematics in *fun* and innovative ways" (Department of Education and Training, 2018) while the 'Science by Doing' similarly is an "inquiry-based approach to lift student *interest* and understanding" (Science by Doing, 2019). As observed, these government-funded programs express having affective intentions to engage students in STEM. However, there seems to be no evidence of how these intentions flow through to the classroom or even a successful connection being made to the affective domain of engagement or the robust literature behind it.

11.8 Affect and STEM

Although not explicitly related to 'affect' or 'affective engagement', Martin-Hansen (2018) explores how a positive or negative science, technology, engineering and mathematics experiences affect the formation of an individual's STEM identity. She clarifies how presenting STEM concepts and ideas is not merely enough to guarantee student interest, enjoyment or that they are deeply internalizing the knowledge. Martin-Hansen explains that STEM concepts are not universal ideas, but rather they are human endeavours that are inevitably sifted through an individual's lenses of personal experience when one is attempting to make meaning of them. Therefore, when learning and teaching STEM-related subjects, it should be acknowledged that an individual's culture and belief system are relevant at all periods of inquiry and problem-solving. If students are to be recruited and retained in STEM fields, they need to have a positive STEM social identity (Martin-Hansen, 2018).

Although there are a considerable number of government funded STEM education programs being implemented throughout Australia, it cannot be ignored that current literature frequently suggests a continuous decline in STEM enrolment as there is a declining interest in STEM-related subjects in western countries (Sharma & Yarlagadda, 2018; Watters & Diezmann, 2013). Additionally, although the importance of STEM to today's society is acknowledged, there still remains considerable skills shortages in STEM-based industries (Watters & Diezmann, 2013). The literature frequently suggests the common goal of 'engaging', 'inspiring', 'motivating' and increasing the 'aspirations' and 'interests' of Australian students to participate in STEM-related subjects. Signified in a STEM article which outlined perspectives of STEM education policies, it was stated that, "a policy centre piece of the Turnbull Government announced in December 2015, to '*inspire*' all Australians—from pre-schoolers to the broader community—to engage with STEM" (Sharma & Yarlagadda, 2018, p. 2003). Similarly, these authors specified that, "governments are committed to train and *inspire* the youth of their nations and produce skilled workforce that would make invaluable contributions to their STEM industries" and also that "declining enrolment trends in STEM education have forced policymakers to take serious steps in creating an *interest* and *motivating* children towards the undertaking of STEM education" (Sharma & Yarlagadda, 2018, p. 2000). In the 2017 STEM Partnerships Forum chaired by Australia's Chief Scientist Dr Alan Finkel, it states that "the challenge for increasing participation in STEM disciplines is building *aspiration*" (Education Council, 2018, p. 46). Although these keys words all insinuate the collective objective of endorsing a positive emotional/affective disposition to STEM participation, it is seldom seen that an authentic investigation into the affective domain of students' engagement in STEM education is thoroughly or deeply explored. Alternatively, what has been observed in the literature, is an almost cryptic application of these emotionally/affectively-inclined words without any distinctive definition. These words are all widely used in the STEM literature without any successful connection being made to their uniting and highly theoretical concept 'affective engagement'.

11.9 Conclusions and Implications

In this chapter we have demonstrated the inherently affective nature of STEM education, and indeed, how many policymakers and educators have seen STEM as a panacea for the affective ills facing the disciplines of mathematics and science. Unfortunately, it is clear that while there has been widespread hope for these *STEM initiatives* to promote participation, interest and engagement in its constituent disciplines, and in turn higher learning outcomes, there appears to have been little detail about how this might be achieved, clarity about why it might work and research to measure its success. Indeed, there is some evidence that participation in science, mathematics and engineering has not improved. Simply repackaging what have historically been unpopular, but important, disciplines (i.e. mathematics and science) in a new "STEM" wrapper will not automatically improve student engagement and therefore, participation and achievement, unless STEM education itself improves from simple integration to a focus on processes as detailed by Lowrie, Logan et al. (2017). Perhaps this is because currently, the complex issues related to engagement, participation and achievement in STEM, and its disciplines, have been dealt with in an overly simplistic manner, and inadequate attention has been afforded to the affective dimension of learning. We think that the emerging work of Lowrie, Logan et al. (2017) on "STEM practices" is a useful way to consider STEM education in a more sophisticated manner, moving beyond the simplistic treatment of STEM as a simple integration of individual disciplines.

This is not to say that a STEM approach may not improve student engagement and participation, but there is a need for more complex research and theorising, particularly now the initial basic work has been undertaken as the euphoria and promise of STEM initiatives were rolled out. Below we suggest some implications for research and practice.

11.9.1 Implications for Research

First, in general, there would seem to be a pressing need for research that pays particular and focused attention to the affective dimension of learning STEM. This would mean moving beyond the assumption that STEM is inherently interesting, motivating and engaging. Importantly, it needs to examine the way affect influences and impacts learning in STEM, but also what and how affective qualities are developed through STEM pedagogies. This would require conceptualising STEM and affect in holistic and complex ways, and not overly simplifying them in the research process and subsequent theorising.

Second, it would seem timely to consider how affective qualities in STEM education are 'learned', and importantly how this relates to the foundation school disciplines of mathematics and science. For example, it is well known that many people dislike mathematics and subsequently disengage from mathematics education, but is this ameliorated by STEM education initiatives? More specifically, is STEM in schools addressing all three dimensions of engagement, or is it just affective and operative (hands-on) and not cognitive because the science and mathematics content knowledge is not being accessed or is not strong enough?

Third, it appears that enrolments in STEM-related fields are still dropping, so there is a need to understand if the supposed engagement and interest engendered by 'STEM' at school actually connects to STEM disciplines in tertiary education. And if this disengagement is due to affective factors (amongst others), how could this be addressed? Perhaps there is a need for longitudinal research on affect and STEM between school and tertiary to further examine this disconnect, especially given the aspirations and hopes for school STEM education to ameliorate this worrying concern.

Of course, there are many more worthwhile avenues for research into the affective domain and STEM education, but it will be important that alongside this research there is careful analysis and theorising. As noted above, the idea of "STEM practices" is one example of how this might be done, and this would appear to be worthwhile as it attends to the actual 'doing' of science, technology, engineering and mathematics, and has relevance for classroom practice in STEM.

11.9.2 Implications for Classrooms

While we do not want to create an artificial divide between research and practice, alongside, and related to, the implications for research, there are some implications for classrooms. Here we list three.

First, if there is a disconnect between the STEM experienced by students at school, and the STEM of the world outside of classrooms, there is a need to reconsider the curriculum. Specifically, how can this be addressed in the classroom through initiatives such as stronger links to industry, and how does the ‘realness’ of school STEM activities impact interest and engagement, and beliefs about mathematics and science.

Second, for a range of reasons it would seem important to prioritise mathematics and science within school STEM learning. Shaughnessy’s (2013) definition of STEM highlighted the foundational nature of mathematics and science, and this has been reiterated by the Chief Scientist in Australia. Furthermore, across the world these two disciplines are fundamental parts of the curriculum, and as such provide the substantive ‘prior learning’ when it comes to studying in STEM. This is not to assume that the nature and quality of pedagogy and learning in mathematics and science does not require attention, but here we are suggesting that improving engagement and interest in STEM will be built on an emphasis on these subjects, including and especially the affective dimension of learning in them. To this end, there is scope with current curricula to do this through syllabus features like ‘mathematical proficiencies’ and ‘scientific processes’.

Finally, the promises of STEM-based reforms will not be realised without specific attention to staff development. Specifically, teachers need time, support and education so they can develop their own STEM practices, and importantly their attitudes, confidence and knowledge. This is not to eschew the need for teachers to develop relevant pedagogical knowledge and skills, but if they are to foster student interest and engagement in STEM, then they need to be interested and engaged in STEM themselves.

11.9.3 Final Comment

Affect is an integral part of learning in any area of the curriculum, and STEM is no different. It is not an appendage that needs to be considered as separate and disconnected for developing knowledge and skills, but rather it is a part of learning that both is shaped, and shapes, what is learned and how it is learned. Furthermore, affective qualities and responses are learned through classroom experiences. It seems to us that in general an agenda for STEM education has largely arisen to try and address diminishing interest and participation in mathematics and science, and at this point it is unclear as to whether this has been effective, apart from largely anecdotal and hearsay accounts from STEM disciples. For this reason we have suggested that it is time for a more theoretically robust and sophisticated understanding of STEM education, that includes, in an integrated manner, the affective domain.

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Chapter 12
Engaging Students in STEM with Non-traditional Educational Programmes: Bridging the Gaps Between Experts and Learners

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Abstract Aligned with the Reasoned Action Model (Fishbein and Ajzen in Predicting and changing behaviour: The reasoned action approach. Taylor & Francis, New York, 2010), the intention to engage in any behaviour (for example, STEM learning) is influenced by the individual's attitudes, societal norms or cues, and perceived control over the behaviour (that is, self-efficacy). Situated cognition theory (Putnam and Borko in Educ Res 29(1):4–15, 2000) adds that physical contexts and social elements are critical to the learning process and eventual knowledge and skill bases. Our chapter draws on these two theoretical frameworks to present theoretical models and supporting empirical evidence that demonstrate the success of place-based educational programmes (for example, museums, national parks) have demonstrated in promoting student interest, value, and aspiration toward pursuing STEM disciplines (Martin et al in J Res Sci Teach 53(9):1364–1384, 2016). Our work, informed by many others in the discipline, has led to the adoption of a model demonstrating that there are progressively more significant levels of return based on the depth-of-engagement that can be identified for the learners. That is, while virtual experiences show positive outcomes, repeated in-person connections with experts and place-based learning experiences lead to the greatest degree of gains in promoting STEM engagement, interest, attitudes, and achievement.

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12.1 Introduction

In the past decade, considerable attention has been given to expanding educational programming to support Science, Technology, Engineering, and Mathematics (STEM) literacy, interest, and career choice (Braund & Reiss, 2006a; National Science and Technology Council, 2013; Prinsley & Baranyai, 2013). Available evidence suggests that the international focus on STEM education and innovation is driven primarily by the belief that STEM-related competencies are critical to technological and scientific innovation, economic prosperity in the twenty-first century marketplace, and our ability to address many of the challenges that will be encountered by current and successive generations (National Academy of Sciences, 2007; Sahin, Ayar, & Adiguzel, 2014; Wagner, 2008). However, there is considerable concern that current methods of recruiting and preparing people for success within STEM disciplines are failing to generate a sufficient number of individuals to meet the current and anticipated demand for high-quality employees in the STEM workforce (Fox & Hackerman, 2003; Goan & Cunningham, 2006; Kanwar, 2010; Suzuki & Collins, 2009). Stated another way, there is widespread agreement among educators, policymakers, and business leaders that STEM competencies are necessary for economic and societal prosperity, but current educational curricula are failing to produce enough highly skilled workers to fill current and projected vacancies in STEM-related disciplines. For example, a 2012 report from the United States' President's Council of Advisors on Science and Technology determined a need to increase STEM majors by 34% to meet the growing demand (President's Council of Advisors on Science and Technology, 2012).

Efforts to better understand the factors that have led to this projected global shortage of qualified STEM workers focuses primarily on illuminating determinants of learners' decisions to pursue post-secondary STEM degrees, persistence in those programmes, and tendencies to seek STEM employment following the completion of a higher education programme (Bamberger & Tal, 2008; Hiller & Kitsantas, 2014; Sahin et al., 2014). While studies have identified a multitude of factors with the potential to influence individuals' decision to pursue STEM education and employment (that is, informal science learning, mastery experiences, task interest, novelty), available evidence suggests that the establishment and maintenance of interest, fostering confidence in STEM-related skills and abilities, and STEM intentions are often the most potent predictors of persistence in STEM-related disciplines (Chemers, Zurbriggen, Syed, Goza, & Bearman, 2011; Hiller & Kitsantas, 2014; Kotkas, Holbrook, & Rannikmae, 2016; Sahin et al., 2014).

Unfortunately, traditional educational experiences are often ineffective in maintaining student interest in STEM domains across the elementary and secondary school years—especially among students from traditionally underrepresented minority groups (Blickenstaff, 2005; Cici, Williams, & Barnett, 2009; Cici & Williams, 2010; Riegle-Crumb, Moore, & Ramos-Wada, 2011; President's Council of Advisors on Science and Technology, 2012; Willis, 1989). Researchers have referred to the longitudinal attrition in STEM interest among female and low-income students as a "leaky pipeline"—characterized by students withdrawing from pathways in the educational system that lead to STEM careers (Watt, 2016). The continued reduction in STEM career interest and intent that occurs as learners progress through the educational system is most striking when examining collegiate achievement statistics for females and minority students. In 2015, Latino students accounted for 13% and African American students accounted for only 9% (National Science Board, 2018) of all Science and Engineering (S&E) Bachelor's degrees. A gender disparity was noted within the S&E broad domain as well. Although females received 50% of all S&E degrees in 2015, only 6% were in Engineering, Mathematics, and Computer Sciences (National Science Board, 2018). Finally, although there is evidence of positive growth trajectories in S&E bachelors' attainment in most categories, the pace is not matching the expected needs projected to meet industry and society demand (National Science Board, 2018).

A variety of theoretical approaches have been applied to address the long-standing gap in positive STEM outcomes for learners—such as the Theory of Planned Behaviour (Ajzen, 1991), Social Cognitive Theory (Bandura, 1997), and Reasoned Action Model (Fishbein & Ajzen, 2010). Review of these models suggests they agree on three key factors that can influence the continued engagement of learners in STEM disciplines. The first primary domain is to raise the interest and affective orientation the learner holds toward STEM topics. The second focuses on ensuring that the learner recognizes that she has the necessary skills and supports to succeed in the domain. Finally, learners need to be able to identify a pathway of pursuing the STEM disciplines (starting with general intention to engage then progressing to actual commitment). We believe informal educational programmes hold great promise to support students in pursuing STEM careers due to the influence that these programmes can have across the educational timeline to inspire positive affect toward STEM disciplines, provide meaningful learning experiences that bolster self-efficacy for STEM, and establish connections with STEM topics and experts who help develop learners' perceptions of the social utility and opportunities in the fields.

12.2 Individual and External Factors Influencing STEM Career Attainment

Following in the tradition of influential approaches supporting the explanation and prediction of self-generated behaviour (for example, Ajzen, 1991; Bandura, 1997; Fishbein & Azjen, 2010), we agree that initial and prolonged engagement in any self-generated activity follows from the formulation of an intention—or plan—to engage in that activity (Fishbein & Azjen, 2010). In support of this basic theoretical proposition, recent work has demonstrated the considerable power of behavioural intent in predicting learners' participation in STEM educational programming. For instance, investigations have repeatedly demonstrated that learners with well-developed behavioural intentions focused on STEM degree attainment (plans to major in STEM fields) are considerably more likely to pursue STEM degrees than learners with weak behavioural intentions (Maltese & Tai, 2011; Tai, Liu, Maltese, & Fan, 2006). The development of durable behavioural intentions is the result of the interactive influence of internal attributes of the learner as well as supportive and debilitating environmental factors.

12.2.1 Internal Student Characteristics

Internally, the establishment of goal-directed behaviour is believed to follow from an individual's overall attitude toward the behaviour (that is, is the behaviour interesting or valuable, will the behaviour lead to positive outcomes) and individuals' belief that they have the skills and resources needed to complete the task effectively (that is, perceived behavioural control). These factors are expected to drive behavioural intention such that more favourable views toward the behaviour and increased efficacy beliefs contribute to stronger behavioural intention and future engagement (Montano & Kasprzyk, 2015).

12.2.1.1 Attitudes and Interest

One of the core propositions of our conceptual framework builds upon a sizable body of evidence noting that behavioural intention is fundamentally tied to their perceptions of the behaviour. From a broad perspective, the willingness to engage with educational content over an extended period is impacted by how well the content captures and maintains their interest (Falk, 1999; Hidi, 2006). Therefore, characteristics of the immediate learning environment and the to-be-learned content are critical in capturing the immediate—or situational—interest of learners which often manifests as the experience of positive achievement emotions and the devotion of attentional resources (Braund & Reiss, 2006a; Hidi, 2006). With repeated exposure to high-quality content, interest can develop into a stable personality disposition that is characterized by positive attitudes toward the content area and a desire to repeatedly engage with content from a particular domain (Hidi & Renninger, 2006). Critically, the ability of educators to capture individual interest early in learners' educational progression is critical to entrance and persistence in the STEM pipeline. Empirical investigations have repeatedly demonstrated that students who exhibit early interest in STEM topics—and maintain that interest throughout their educational career—are more likely to pursue and complete degrees in STEM-related disciplines compared to their less interested counterparts (Andersen & Ward, 2014; Maltese & Tai, 2010, 2011; Sadler, Sonnert, & Hazari, 2012).

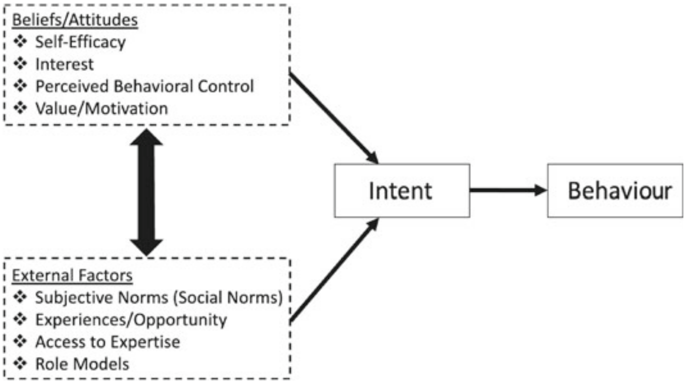

Fig. 12.1 Adapted reasoned action model

12.2.1.2 Self-efficacy

Our conceptual framework recognizes the importance of self-efficacy beliefs in STEM persistence and long-term success. Simply stated, the construct of self-efficacy refers to an individual's belief about their ability to successfully implement the behaviours that are needed to reach desired outcomes (Bandura, 1977, 2005, 2006). Students who are confident in their abilities are better able to organize and implement the cognitive, social, emotional, and behavioural skills required for successful performance within academic settings (Bandura, 1977; Multon, Brown, & Lent, 1991). Consistent with findings in the broader educational literature, recent work has established the existence of a positive association between self-efficacy and STEM persistence and retention. Studies have shown that learners with high STEM self-efficacy exhibit increased interest in STEM-domain and are more likely to develop intentions to pursue training and works in STEM fields compared to their peers who question their STEM-related competencies (Chemers et al., 2011; Lent, Lopez Jr, Lopez, & Sheu, 2008; Lent, Sheu, Gloster, & Wilkins, 2010; Perez, Cromley, & Kaplan, 2014). Collectively, when a student believes she can be successful in STEM activities (for example, through positive learning experiences), she is more likely to approach the STEM discipline, develop a more positive outlook toward the discipline, and remain engaged with the field (see Fig. 12.1).

12.2.2 External Supports and Influences

The behavioural outcomes from the RAM framework are shaped by essential experiences and interactions that occur at the cultural, societal, and interpersonal levels. These external influences directly impact behavioural intent through exposure to the discipline as well as by having the value and importance of the field communicated to the learners. Students who repeatedly interact with positive role models, engage in STEM-related activities, and are shown that they can be successful in STEM fields are more likely to develop positive intent (Bandura, 2005). However, in addition to this, direct influence on STEM intent, external supports, and barriers indirectly influence STEM access and pursuit by influencing the attitudes and beliefs of developing learners.

As outlined in the previous section and illustrated in Fig. 12.1, learners' decisions related to STEM pursuit is based on their interests and perceived efficacy. Unfortunately, research conducted by Braund and Reiss (2006a) indicates many students in developed countries are not interested in science, suggesting a low probability of entry into a STEM-oriented field of study. Research suggests these attitudinal barriers are often linked to pedagogical shifts in STEM teaching and cultural influences (for example, stereotype threat) students experience throughout their educational journey, noting a significant interest decline between primary and secondary education (Braund & Reiss, 2006a; Christidou, 2011; Potvin & Hasni, 2014). As such, the attempt to stave off interest decline and increase positive reception of STEM by connecting learners to informal and place-based learning experiences is expected to impact on eventual intent and behaviour by influencing both the external factors and beliefs and attitudes represented in Fig. 12.1.

Students' perceptions of what may be classified as a STEM career is radically shaped by educational curricula and standards (Finson, 2002; Scherz & Oren, 2006). However, science educators and students report that classroom science learning materials and pedagogical strategies are boring, irrelevant, or outdated and primarily serve those who are already invested in the discipline (Braund & Reiss, 2006b; Goodrum, Rennie, & Hackling, 2001; Sjøberg & Schreiner, 2010). Fortunately, the opposite is true of science education outside of the classroom (Braund & Reiss, 2006a). Whether it be via media, museums, citizen science programmes, active learning curriculum supplements, or nature reserves, STEM-centric education in informal learning environments generates excitement, interest, and persistence in working with contextualized content (Bamberger & Tal, 2008; Braund & Reiss, 2006a; Holmes, 2011; Hiller & Kitsantas, 2014), which can promote greater content mastery and commitment toward STEM careers (Falk, Dierking, & Foutz, 2007).

12.3 Situated Cognition, Social Cognitive Theory, and Constructivism

Situated cognition, or situated learning, among other theoretical bases of knowledge construction, aids in articulating the strengths of exposing students to expert role models and influential environments to solidify beliefs and attitudes toward STEM content. Derived from a foundation of ecological psychology, situated cognition proposes that all knowledge is intertwined within actions, contextualization, and functionality (Barab & Roth, 2006). Not only is the individual–environment interaction a critical component, but situated cognition emphasizes the interconnectedness of content, function, setting, and active participation in learning (Cobb & Bowers, 1999; Greeno, 1997). The situated cognition models often encourage inquiry-based approaches to promote problem-solving strategies and informal reasoning found within scientific endeavours (Bereiter, 1994; Duffy & Cunningham, 1996). Historically, prominent theories of learning also justify situated learning perspectives. Social cognitive theory (Bandura, 1997, 2001, 2002) proposes that social modelling (proxy agency) expands learner control to account for the expertise of others to obtain knowledge and skills, all with the goal to further academic growth. The sociocultural constructivist frameworks aligned with Vygotsky (for example, 1978) that promote learning in a zone of proximal development or scaffolding also place value in connecting learners to real-world problems, interacting with experts in domains, drawing upon social artifacts to support learning, and engaging in shared experiences with peers and educators to frame a foundation of cognitive modelling within a discipline.

The general tenet of constructivism is that learning is an active process of knowledge construction supported by instruction instead of knowledge acquisition via communication (Duffy & Cunningham, 1996; Kintsch, 2009). This general approach encourages students to construct their knowledge and negotiate their interpretation of content to promote refinement of concepts (Cobb & Bowers, 1999). Furthermore, engaging in collaborative learning and situational learning facilitate the necessary meaningful learning and knowledge acquisition required for conceptual change to occur (Novak, 2002).

The active learning paradigm highlighted by Chi (2009) operationalizes primary assertions regarding deep learning presented by situated learning theorists. The paradigm posits that deeper learning is attainable when learners are active in the learning process by personalizing their content understanding, rather than remaining passive observers (Chi, 2009). Specifically, she promotes the utility of the “interactive” learning formats, in which learners engage in multiple interactions as they manipulate their environment, generate hypotheses, and build upon knowledge co-constructed with their partner/mentor (Chi, 2009). Moreover, repeated content exposure with expert support over time enables more profound engagement with content, allowing for significant cognitive associations among the content, functionality, and setting to instantiate (Chi, 2009; Osborne & Wittrock, 1983; Wittrock, 1992). Therefore, multiple exposures to learning in contexts with interactive activities should be most beneficial for deep understanding.

12.4 Successful STEM Engagement Through Informal Learning Resources

To maintain interest and engagement in STEM disciplines requires a steady and developmentally appropriate level of exposure to topics that are often unrealized in traditional school settings. The barriers to fostering student interest and appeal in STEM topics vary widely, but the most commonly referenced issues include (a) lack of expertise by teachers—mainly before middle school (Hall, Dickerson, Batts, Kauffmann, & Bosse, 2011), (b) "crowded" curriculum calendars (that is, imposed by the multitude of curriculum standards that overwhelm the instructional day) that limit time to engage in deep learning experiences (Hossain & Robinson, 2012), and (c) funding limitations to support resource-heavy learning experiences (Hossain & Robinson, 2012; Strayhorn, Long, Kitchen, Williams, & Stenz, 2013). While we agree that the standard K-12 school environment is essential for developing and supporting functional STEM literacy, we also recognize the importance of ensuring that teachers and students have options to go beyond standard curriculum offerings by connecting with experts, relevant artifacts, and situationally specific learning experiences that will foster greater awareness, continued interest, and improve the potential for inspiring career pursuit in the sciences and math. We concur with Falk and Dierking (2000), informal education settings environments address the complex nature of learning in cognitive, affective, social, and behavioural manners. This holistic approach to learning enables learners to actively construct their understanding of STEM topics in unique and meaningful ways (Bamberger & Tal, 2008).

12.4.1 Non-traditional Classroom Experiences

A multitude of non-traditional classroom options are available to educators, administrators, and parents to aid in the cultivation of STEM interest, knowledge, and confidence. The highlighted exemplars, we briefly review below are merely representative models and strategies designed to illustrate the potential for bolstering STEM access for more learners within the frameworks of Reasoned Action Model and situated learning that are expected to be adaptable to specific contexts, contents, or developmental ages.

Prominent examples of applying RAM in a way that bolsters STEM learning by incorporating external curriculum, resources, and training to augment standard classroom curricula and structures are programmes such as Project Lead the Way (PLTW) and citizen science programmes. PLTW is a not-for-profit company located in the U.S. that develops curricula for students ranging in ages from early childhood through secondary education, focused on learning STEM topics through real-world applications and problem-solving (Tai, 2012). The stated objective of PLTW is to elevate student motivation and interest in STEM engagement, which will in turn promote math and science abilities (Hess, Sorge, & Feldhaus, 2016; Tai, 2012), which has a long-term goal of shaping the future career choices toward STEM-based careers (Hess et al., 2016).

A central function of the PLTW model is specific and intense training for educators and administrators to deliver the programmed content in their schools, as well as cultivate a healthy STEM ecosystem. Utilized PLTW content creates a cohesive instructional path for students informed through classroom experiences, contemporary research, and collaborative experiences with academic and industry experts

(Project Lead The Way, 2019). Literature reviews examining the efficacy of PLTW indicated increases in student motivation and interest toward STEM content in middle grades (roughly ages 11–14), and secondary school grades (ages 14–18; Hess et al., 2016; Tai, 2012). Furthermore, a multilevel analysis comparing high school aged graduates of PLTW, students declining to join the programme, and students without access to the programme revealed PLTW graduates were most likely to pursue STEM majors (Sorge, 2014).

PLTW is an example of a formal external curriculum augmenting instructional opportunities in classrooms. Citizen scientist programmes are less formally defined and structured but have a similar programmatic goal—to engage learners in real-world scientific pursuits supported by experts within a supported instructional setting. Citizen science programmes utilized in coordination with educational environments empower students to not only construct their knowledge through "doing," but also introduces them to what "real scientists" are outside of classroom experiences. Traditionally, citizen science programmes allow for general public amateur scientists to collaborate alongside professionals and institutions in various fields of research such as astronomy, ecology, and geology (Hiller & Kitsantas, 2014; Snäll, Kindvall, Nilsson, & Pärt, 2011). One example programme engaged preadolescents working alongside experts in the field collecting data on horseshoe crab life (Hiller & Kitsantas, 2014). Naturally, the utilization of citizen science initiatives with students allows for unique informal science education experiences non-accessible within traditional classroom frameworks. Citizen science participation enhances students' mastery experiences in STEM through modelling, scaffolding, and feedback from subject matter experts (Eberbach & Crowley, 2009; Hiller & Kitsantas, 2014). The higher levels of engagement afforded by citizen science involvement have been seen to increase attitudes and interest, in turn positively influencing academic achievement, STEM expectations, and career choice (Brossard, Lewenstein, & Bonney, 2005; Hiller & Kitsantas, 2014).

12.4.2 Place-Based Learning Experiences

Informal and non-traditional learning experiences are critical to promoting STEM career intentions through heightening scientific interest, purposeful participation, and STEM identity development (Friedman, 2008; Michalchik & Gallagher, 2010). Historically, one of the most common ways to supplement student engagement, foster interest, or broaden understanding is to visit an educationally relevant location such as a museum, nature preserve or park, or national historic location (Braund & Reiss, 2006b; Falk, Donovan, & Woods, 2001; Martin, Durksen, Williamson, Kiss, & Ginns, 2016; Rowe, Lobene, Mott, & Lester, 2017). Defined simply, place-based learning is the integration of traditionally "classroom-based" content into a meaningful context in the local environment or community to provide a more interactive and naturalistic setting for student learning (Sobel, 2004). Research has demonstrated that place-based learning can be an effective method for building student engagement, motivation, and achievement. A variety of schools implementing place-based learning curricula—for example, those in large urban areas as well as isolated island communities in northeastern sections of the United States, and rural areas of Australia—have been met with both increases in student motivation and engagement, as well as community support (McInerney, Smyth, & Down, 2011; Smith & Sobel, 2010).

The power and potential for learning in settings such as museums, national parks, and historical monuments is seen by the frequency by which they are referenced as a critical factor contributing to educational advantages observed for children from higher socioeconomic backgrounds. Children who frequently visit museums have fun, parks, landmarks, and other informal learning spaces tend to have a broader educational background before and during their K-12 training (Holmes, 2011). As such, they have a more contextually relevant basis for several domains of inquiry, including STEM topics (Martin et al., 2016). The fundamental advantages afforded to learners who have consistent access to these supplementary informal learning outlets tend to be both broader and deeper representations for the content (Bamberger & Tal, 2008; Holmes, 2011). Beyond mere exposure to more—and often better—content, the experience of learning in museums and parks is that the learning event can be more enduring due to the additional cognitive links that are established for the content presented (Barab & Roth, 2006). That is, learning in situ enables the learner to encode significantly more rich and vibrant representations of the content that form more durable long-term memories.

Research exploring the impact of visiting museums to support STEM learning gains have demonstrated that merely visiting a museum is a positive experience to support interest, learning, and identification with science (Adams & Gupta, 2013). However, learning benefits are more likely to be observed when the time in the museum setting when additional engagement can be supported more fully with prolonged or repeated experience with the institution (for example, as a participant supporting programming at the location; Bamberger & Tal, 2008; Cassady, Thomas, Potts, & Heath, 2017). Structuring the experience at museums (for example, educationally focused engaging activities or questions within the museum space) has also been demonstrated as a critical factor in ensuring that time spent in the museum is maximally effective in promoting learning gains, and students leave the experience with the target content more fully realized (Yoon, Elinich, Wang, Van Schoomeveld, & Anderson, 2013). Similarly, researchers examining class-based field trips or visits to museums are beneficial, but the efficacy of the learning experience was improved when accompanied with post-visit activities or programming (Anderson, Lucas, Ginns, & Dierking, 2000).

One successful nationwide project in the U.S. was the National Park Foundation's "First Bloom" programme. The programme demonstrated that traditionally underserved minority populations could become more invested and engaged in STEM disciplines through repeated exposure to meaningful learning in natural learning spaces (that is, National Parks). The programme involved connecting children from inner-city Boys and Girls Clubs with a nearby National Park through a structured process focused on service learning and promoting sustainable environmentalism. A year-long intervention and evaluation study examining that programme demonstrated that students who were engaged in the programme showed more favourable attitudes toward National Parks and environmentalism, and an increase in their perceived efficacy to "make a difference," and their intent to continue to engage in behaviours that support the environment and/or their National Parks which translated into the identification of behaviours that were supportive of environmental needs (Aurah & Cassady, 2011). Detailed review of the successes in the programme demonstrated that the most substantial gains were noted in the conditions where the children in the programme were engaged in repeated interactions with the National Park representatives (for example, field trips and visits by park rangers to their clubs) as well as active experiences where they were clearly improving and supporting the park (for example, planting sustainable native plants, clearing invasive species that compete with native plants and animals, creating learning experiences for children with disabilities to engage in the parks; Cassady, Ferris, & Kornmann, 2009).

In a related programme focused on adolescents (known as the "Park Stewards" programme), our team evaluated the effects of a place-based multisession programme to promote environmental behaviours among adolescents connected to regionally located National Parks. Across the 20 evaluated National Park programmes reviewed in our work (reaching over 2,800 students), we documented that the "sweet spot" for seeing that level of buy-in with traditionally underrepresented minority students connecting to STEM behaviours between 4 and 6 programmatic experiences—with at least 2 of them in the natural learning space (as opposed to the school; Aurah & Cassady, 2011).

An example of the Park Stewards programme examined varied levels of engagement serves as a model for reviewing the potential of place-based learning within our framework. Students at a high school proximal to Saguaro National Park (within walking distance of the school) in the southwestern state of Arizona in the U.S. participated in a year-long educational experience. The results of that study demonstrated significant differences among students with three profiles of engagement with the National Park learning environment. Core members ($n = 33$) attended multiple learning events led by scientists and rangers from the park (discussing environmental science topics, enacting protections for the saguaro). Partial engagement participants ($n = 15$) attended only one session, and a control group of students from the school who did not attend any events ($n = 37$) were also surveyed at the beginning and end of the academic year. As shown in Fig. 12.2, the critical observation was that a single place-based learning event in the National Park was sufficient to demonstrate an increase in students' attitudes and perceived efficacy to support National Parks and the environment. However, only students who had attended multiple programmatic experiences at the National Park focused on environmental impacts humans can make demonstrated significant gains in their behavioural intent and subsequent behaviour to continue engaging in environmentally supportive activities to preserve National Parks and local natural resources.

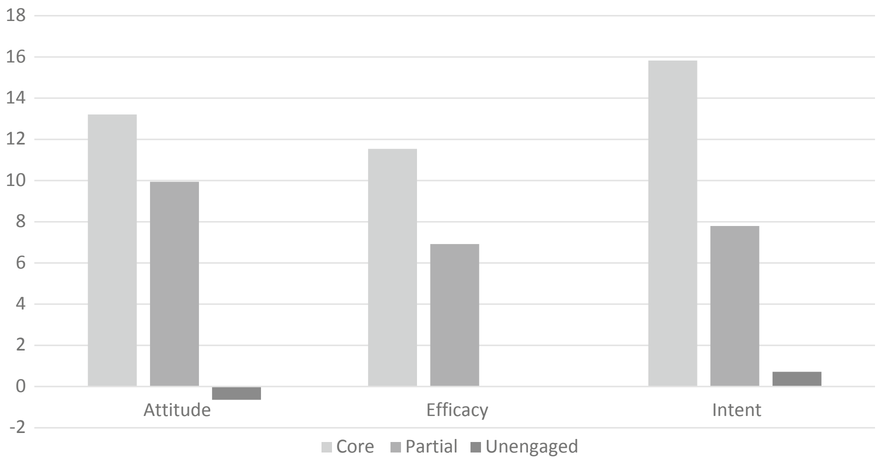

Fig. 12.2 Pre–post percent growth by level of engagement (National Park Foundation Park Stewards Programme)

12.4.3 Electronic Field Trips

Another programmatic approach to informal STEM learning we have been engaged with has been the use of Electronic Field Trips (EFTs), and several “spin-off” iterations of distance-based learning events assisted through technology (for example, Cassady, Kozlowski, & Kornmann, 2008). The primary advantage afforded by EFTs is the ability to connect learners who are isolated from meaningful place-based learning experiences to unique learning environments. While we hold the perspective that virtual access to contextually relevant learning spaces (for example, museum, natural locations) does not afford all the benefits that in vivo experience affords, EFTs do hold promise to support learning for a broader population who do not have immediate access to those locations. In particular, we have noted in prior empirical work that EFTs are effective at capturing the interest of students by inducing what Dewey referred to as their “natural learning impulses” (see Cassady & Mullen, 2006). In addition to sparking interest, research with EFTs has demonstrated gains in student awareness and understanding of STEM topics (for example, formation of the Grand Canyon, geologic science in caves, working in low-gravity environments, migratory patterns of whales) through the use of programmatic elements that encourage exploration of content developed by content and pedagogical experts. In those studies, the critical elements supporting learning and academic gains through distance technology included (a) repeated exposure to the core scientific content and (b) aligning the content of the EFT with classroom experiences by providing lesson support for teachers (Cassady et al., 2008).

While research into STEM learning has demonstrated that learner interest in STEM can be sparked by merely watching videos of scientists (for example, Wyss, Heulskamp, & Siebert, 2012), we advocate for a more structured and strategic approach to virtual learning experiences in STEM. Just as guided field experiences in a museum with a master docent will be connected to stronger learning and understanding (Bamberger & Tal, 2008), having explicit connections among learning goals for students and the virtual educational experiences will make the virtual experience more effective and durable. Exemplary approaches to this have been demonstrated in programmed learning environments that directly tie the academic learning standards or objectives to the programme content, bridging the common gap of expertise in science and expertise in education (Cassady et al., 2008). Teams formed to support this generally have a collaborative process that brings the content experts into connection with pedagogical experts and ensures that the classroom teacher can incorporate the deep and rich science content into their classrooms effectively. Strategies that support this connectivity include providing lesson plan suggestions to complete both before (to provide background context) and after (to have extension learning activities) the planned virtual event(s).

In a series of studies conducted in coordination with the Smithsonian Institution's National Air and Space Museum (for example, Cassady et al., 2017), we confirmed that STEM learning could be supported at a distance provided these structures were in place. The impact on learners was demonstrated in a national sample of middle-grade learners (for example, ages 11–15) who watched a live television or web streaming broadcast of a 30-min. STEM-focused programme (for example, eclipse, science of flight) connecting learners with experts in various museum experts. The student survey contained three subscales scored on a 5-point Likert-type scale focused on positive attitude and interest in the learning event (*interesting, fun*), efficacy related to learning from this modality (*learned a lot, know more than before*), and the intent and desire to engage in future STEM activities (*do another programme, visit Smithsonian Air and Space Museum*). As shown in Table 12.1, the relationships between the three broad subscales (Attitude, Intent, Efficacy) were moderate to high (Tabachnick & Fidell, 2013). In particular, the most significant predictors of student's desire to visit the museum or "do more science" were their ratings of how exciting or fun the STEM-in-30 show was to watch and their statement of how much they would like to view another session. Review of patterns across specific programme offerings provided by STEM-in-30 demonstrated slight differences in attitude, intent, and efficacy. Careful review of the differences demonstrated that while specific topics are certainly more appealing to students (for example, race cars and rockets), the critical features that were most relevant to promoting interest and intent were (a) clarity in programme messaging, (b) connection to their standard science topics (for example, vocabulary tie-ins), and (c) introducing STEM professionals in a more accessible format. Despite

Table 12.1 STEM-in-30 student survey Pearson's r correlations ($n = 68$)

	Attitude	Intent	Efficacy
Attitude	1.000		
Intent	0.714	1.000	
Efficacy	0.606	0.540	1.000
Subscale mean	3.14	3.09	3.56

the programme variations, the overall means of STEM-in-30 participants' responses indicated that their highest average rating was in the domain of 'efficacy,' which was a measure of their perception of having learned from these virtual STEM programmes.

12.5 Conclusion

Our primary conclusions based on the work we have reviewed as well as created is that the utility of non-traditional, informal, or virtual forms of presenting STEM content is centred on three primary guiding principles when attempting to augment traditional methods of delivering STEM content to children and adolescents. First, activating interest and promoting perceived self-efficacy toward the domain is critical to ensuring long-term behavioural intent and engagement. Second, exposing students to STEM experiences that provide an engaging presentation, real-world applications, opportunities to interact with experts, or access to varied representatives from professional STEM disciplines can bolster the positive attitudes (interest) and self-efficacy factors that promote STEM commitment. Third, we identify a continuum of engaging learning activities that recognizes that while all the forms of instructional support or augmentation outlined in this chapter show promise for positive impact, some methods exert considerable influence in behavioural intent and eventual engagement.

When reviewing the first two conclusions, a testable hypothesis is clearly arising. In the revised RAM framework, we centred an earlier portion of this chapter around, we identified the Internal Characteristics (that is, Attitudes/Interest, Efficacy) and External Factors as equitable in their influence on one another as well as behavioural intent. We maintain that these are both key factors, but as we continue to review the data, an alternative model may be relevant. It is possible that the primary influence of the External Factors—at least the ones we focus upon—is almost entirely mediated through Internal Characteristics. That is, while all these supportive events and positive learning experiences are indeed powerful and useful to long-term success, the primary pathway through which this is realized is through the development of interest, positive attitudes, and perceived self-efficacy of the learner (see Fig. 12.3). We maintain that a bidirectional influence is still relevant when considering External and Internal Factors, but the reimagining of the model as displayed in Fig. 12.3 promotes attention to the importance of not only providing positive experiences so that content can be conveyed—but considering the promotion of positive attitudes, interest, and self-efficacy in those programmatic events.

Finally, we believe that the value of varied forms of STEM instructional support is determined by the level of engaged learning prompted for the student, as conceptualized in Chi's (2009) representation of active learning. Specifically, as the level of interaction between the learner and the content increases—with the learner becoming a more central figure in the learning scenario, the level of depth of learning increases. We propose that considering this continuum of engagement can promote learning benefits of informal, non-traditional, and place-based learning experiences.

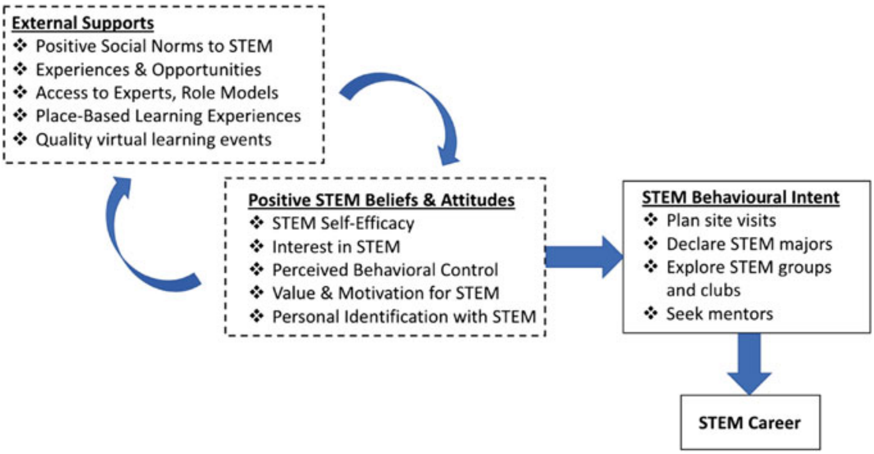

Fig. 12.3 Pathways to promote STEM engagement with non-traditional educational programmes

Based on our work and the work of others, we propose three primary dimensions of consideration when attempting to review the likelihood of meaningful long-term student engagement supported by specific STEM programmes: frequency of contact, "location" of experience, and personal activity. While these dimensions can be separate and vary independently across STEM instructional activities, we anticipate that the learning benefits will be best estimated when examining the interaction among these three. As proposed in Fig. 12.4, we anticipate that the best representation for programme utility will come as an interaction effect between the level of personal engagement and location. While progressively higher levels of personal engagement and situated learning are positive, the greatest gains will be realized as learners are

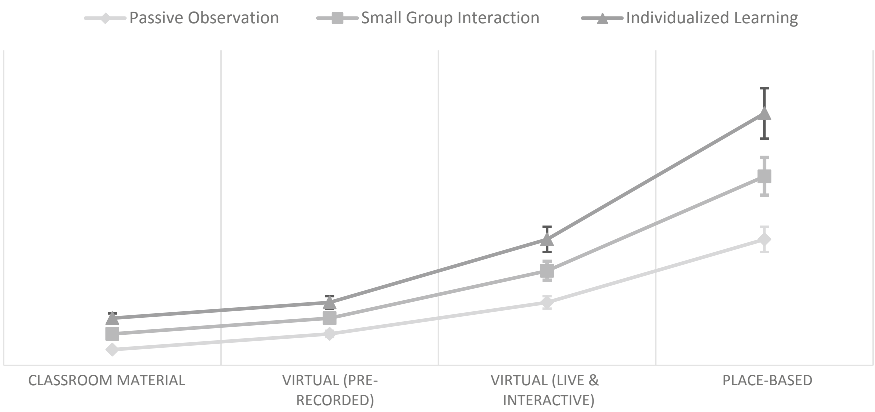

Fig. 12.4 Proposed learning outcomes based on frequency, location, and personal engagement

personally engaged with the content on location. That is, individually driven learning experiences in a STEM-focused learning lab (for example, science camp at a museum) should provide higher levels of long-term STEM commitment than less personally engaged or place-dependent learning situations (for example, online video review of science experiment). We believe the influence of frequency is such that it merely bolsters the effect generated (denoted in Fig. 12.4 with error bars), wherein repeated events strengthen the potential positive impact—provided each repetition has the same value and utility as previous events.

Collectively, we anticipate that as educational support materials expand the delivery options available to teachers and students, greater success in promoting STEM pathway resilience can be obtained. However, continued success in promoting the long-term success of learners in pursuing and succeeding in STEM fields are proposed to be influenced by providing learners with engaging STEM experiences that improve their overall attitudes and beliefs about their own STEM potential. We believe that this is maximized as learners become more directly connected to the disciplines of interest by becoming more personally engaged, directly connected to STEM-relevant places (for example, museums, natural spaces, laboratories), and are exposed to these experiences repeatedly.

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Chapter 13
Threshold Concepts in Primary School Maths and Science: An Investigation of Some Underlying Ideas of STEM

Steve Thornton

Abstract Threshold concepts are those which are characteristic of the discipline, and without which students are able to make only limited progress in developing disciplinary ways of thinking. They are characterised by being: transformative, in that once understood, they result in a significant shift in the perception of a subject; irreversible, in that the change of perspective is unlikely to be forgotten; integrative; in that they expose the previously hidden relatedness of ideas; bounded, in that they open up new conceptual spaces, and; potentially troublesome, in that they are hard to acquire. This chapter examines curriculum resources from the *Primary Connections* and *reSolve: Maths by Inquiry* projects and proposes some threshold concepts in primary mathematics and science. The identification of threshold concepts is important for the research community, for educational designers and for teachers as explicit attention to the concepts may help to address the misconceptions that often lie at the heart of the troublesomeness of concepts encountered in higher education.

13.1 Introduction

The notion of threshold concepts arose in the study of teaching and learning in university environments, as part of the UK-based Enhancing Teaching and Learning Environments project (ETL) (Meyer & Land, 2003). It gave a theoretical framework for studying those concepts considered crucial for students' understanding of a subject area and hence for the way university lecturers approached instruction. Meyer and Land considered a threshold concept "as akin to a portal, opening up a new and previously inaccessible way of thinking about something". The study of threshold concepts has become a growing field of research in higher education internationally yet has received little or no attention in school education.

In school mathematics an emphasis on the importance of big ideas was stimulated by the US National Council of Teachers of Mathematics recommendation (National Council of Teachers of Mathematics, 2000) that "teachers need to understand the

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big ideas of mathematics and be able to represent mathematics as a coherent and connected enterprise" (p. 17). Yet there was no discussion of what was meant by the notion of a big idea, nor of what those big ideas might be. Charles (2005) provided the first definition of a big idea in school mathematics as "a statement of an idea that is central to the learning of mathematics, one that links numerous mathematical understandings into a coherent whole" (p. 10). Following a discussion of the elements of this definition, Charles then provided a list of 21 concepts from all strands of the school mathematics curriculum that might be considered big ideas.

Meeting at an international symposium in PuRkwa Loch Lomond to set out the principles that should underpin the science education of all students throughout their schooling, a group of 10 invited experts distilled scientific knowledge into guiding principles that could be used to explain a variety of scientific phenomena (Harlen, 2010). The goal was to address the issue of students seeing science as a series of endless disconnected facts by describing ten big ideas *of* science and four big ideas *about* science that cut across traditional boundaries and that enable students to begin to see the bigger picture of science.

The key aspect of what have traditionally been called big ideas in school mathematics and science is therefore that they serve to connect and integrate. The emphasis on connection and integration is also evident in the relatively new discourse about big ideas in STEM education (Chalmers, Carter, Cooper, & Nason, 2017) where they are considered "central to the understanding of STEM across a range of fields and taken together represent models of our world as provided by the STEM disciplines" (p. S27). In contrast, threshold concepts do not only serve to connect or integrate—they transform the way we think about something, serving as a portal once grasped, or as a block to progress until grasped. This chapter explores the relationship between threshold concepts and big ideas in primary school STEM education, using resources from *Primary Connections: Linking Science with Literacy* (Australian Academy of Science, 2019a) and *reSolve: Mathematics by Inquiry* (Australian Academy of Science, 2019b) as data sources for the identification of potential threshold concepts in STEM. Specifically, the chapter asks: *What are some potential threshold concepts in primary school mathematics and science? In what way do these concepts act as a portal to transform students' thinking?*

13.2 Threshold Concepts

Meyer and Land's (2003) discussion with lecturers in a range of fields in higher education resulted in the identification of five characteristics of threshold concepts. They suggested that threshold concepts are likely to be

1. Transformative, in that understanding of a threshold concept represents a significant shift on one's perception of a subject. This might be a shift in understanding, values, or indeed the way in which one views the world;

2. Irreversible, in that the change of perspective is unlikely to be forgotten. The irreversibility of threshold concepts is evident by the difficulty often encountered by experts attempting to look back at their own learning in a subject area to identify the difficulties faced by students learning for the first time;
3. Integrative, in that understanding them requires pulling together bits and pieces of knowledge into a conceptual whole, and that threshold concepts potentially expose the previously hidden interrelatedness of ideas. They may bridge concepts within a discipline, or in some cases across disciplines;
4. Troublesome, in that they are likely to be difficult for students to understand. Coming to understand a threshold concept may require letting go of previously comfortable positions, encountering problematic ideas in potentially disconcerting new situations. Such previous knowledge may be ritualised or tacit in that it can be devoid of meaning or application; and
5. Bounded, in that threshold concepts sometimes serve to delineate the academic territory of a discipline. They are likely to operate at the borders of a discipline and open new conceptual spaces.

More recently, threshold concepts have also been described as liminal (Meyer & Land, 2006), in that they represent a transition from one state to another, where learners may oscillate between new and old ways of understanding. For example, adolescence is often described as a liminal state, with adolescents oscillating between adulthood and childhood depending on the context.

Given the elementary nature of school science or mathematics, it is unlikely that any concepts encountered by students will push the boundaries of the subject or lead to new conceptual spaces. Hence, this paper focuses on the first four of these characteristics—transformation, irreversibility, integration, and troublesomeness—recognising that all four may not always be present in a given threshold concept. The following two examples from higher education teaching and learning, one from mathematics and one from chemistry, expand on each of these characteristics.

13.2.1 Limit as a Threshold Concept

A limit is a mathematical concept first encountered by students in the senior secondary years of school, then more formally in undergraduate mathematics education as a fundamental idea underpinning the study of calculus. The concept of limit was identified by Artigue (2001) as an "epistemological obstacle", or "breach in the development of mathematical knowledge" (p. 210). Arguing that mathematical knowledge does not develop in some linear, continuous process, Artigue suggests that intuitive knowledge and knowledge that has previously served to adequately explain phenomena or solve problems in a limited range of situations may become an obstacle for students learning challenging new concepts.

In the case of a limit, Artigue (2001) identified three specific issues in students' prior knowledge that might serve as epistemological obstacles:

1. The everyday meaning of limit suggesting a barrier or final term;
2. The overgeneralisation of properties of finite processes to infinite processes; and
3. The overemphasis on a geometry of forms, making it difficult for students to appreciate the interaction between numerical and geometric settings.

Scheja and Pettersson (2010) studied students' conceptual difficulties with limits empirically by asking undergraduate engineering students to describe their understanding of limits and integration in a written reflection and subsequently in an interview. They identified these as troublesome concepts with students' initial responses describing procedures to be carried out and a small number of connections such as the integral being the area under a curve. When prompted in an interview situation, they began to shift their views by contextualising the ideas in a way that drew attention to conceptual dimensions. Scheja and Petterson argued that by asking students probing questions about the concepts of limit and integral, "the framing of the entire topic changes" (p. 236). The concept of limit and the related concept of integral were simultaneously troublesome and transformative, and integrative in that they prompted students to connect ideas in previously unrecognised ways.

13.2.2 Atomic Structure as a Threshold Concept

Park and Light (2009) identified atomic structure as a threshold concept in college-level chemistry. Previous research had shown that few students developed an understanding of atomic structure that extended to a quantum model and had identified the difficulty faced by students in letting go of an orbital model of electrons in favour of an electron cloud or probability distribution model. Park and Light describe how one student, despite being a high achiever, was unable to reconcile the dumbbell shape of a p-orbital with his understanding of an orbital as the path followed by an electron rather than a probability distribution, stating that it makes no sense because the electron would have to crash into the nucleus of the atom. Based on their study of the troublesome nature of coming to understand atomic structure, Park and Light identified the probability of finding electrons and energy quantization as key components of the threshold concept of atomic structure. These two ideas enable students to integrate the nuclear model of an atom, the concept of orbitals, and quantum theory into a more coherent understanding of atomic structure.

Threshold concepts are simultaneously troublesome to understand and gateways for further understanding. The examples drawn from mathematics and chemistry show that coming to understand threshold concepts such as limit and atomic structure is troublesome in that students cling to intuitive ideas or knowledge that has become part of their conception of the subject. But understanding these concepts opens gateways to understanding more sophisticated ideas in areas such as mathematical analysis and quantum mechanics. The next section briefly reviews the literature relating to so-called big ideas in school mathematics and science, asking to what extent these big ideas might also be called threshold concepts.

13.3 Big Ideas in School Mathematics and Science

Although not expressed as such, the importance of teachers understanding the "big ideas" of mathematics was first highlighted by Felix Klein in his seminal lecture series published as *Elementary Mathematics from an Advanced Standpoint* (Klein, 1939). Klein's goal was to address the "double discontinuity" experienced as first in the transition from high school to university and secondly in the transition back to school as a teacher.

> The young university student found himself, at the outset, confronted with problems, which did not suggest, in any particular, the things with which he had been concerned at school. Naturally he forgot these things quickly and thoroughly. When, after finishing his course of study, he became a teacher, he suddenly found himself expected to teach the traditional elementary mathematics in the old pedantic way; and, since he was scarcely able, unaided, to discern any connection between this task and his university mathematics, he soon fell in with the time honoured way of teaching, and his university studies remained only a more or less pleasant memory which had no influence upon his teaching (Klein, p. 1).

Klein (1939) argued for the importance of teachers approaching school mathematics with a deep knowledge of foundational concepts including the fundamental properties of number such as commutativity, associativity, and distributivity and concepts such as equivalence and inverse. Ma (1999), in her study of the mathematical knowledge of teachers in China and the United States, similarly argued for the importance of teachers having a profound understanding of fundamental mathematics.

In his seminal paper on big ideas of school mathematics, Charles (2005) argued that ideas such as those described by Klein (1939), Ma (1999) and by the National Council of Teachers of Mathematics (2000) should form the basis for one's mathematics content knowledge, one's teaching approaches, and for the mathematics curriculum itself. He argued that understanding big ideas enables one to see mathematics as a coherent set of ideas rather than a series of disconnected facts, skills, or concepts. They enable the connection of concepts across grades, reduce the amount that must be remembered and promote transfer of learning.

Charles (2005) identified 21 big ideas across the content strands of the mathematics curriculum. For example, equivalence is the idea that "any number, measure, numerical expression, algebraic expression, or equation can be represented in an infinite number of ways that have the same value" (p. 14). Estimation is the idea that "numerical calculations can be approximated by replacing numbers with other numbers that are close and easy to compute with mentally (and) measurements can be approximated using known referents as the unit in the measurement process" (p. 17). But should equivalence and estimation, or some or all of the remaining 21 big ideas, be considered "threshold concepts"?

It is beyond the scope of this chapter to give a detailed analysis of the remaining 19 big ideas described by Charles (2005), but both equivalence and estimation can also be considered threshold concepts. In the case of equivalence, there is extensive research to suggest that students often view the equals sign as an instruction rather than a relationship (e.g. Alibali, Knuth, Hattikudur, McNeil & Stephens, 2007). Hence, they will solve a problem such as $12 + x = 11 + 5$ by first evaluating

11 + 5 and then subtracting 12, rather than looking at the relationship between the numbers on the two sides of the equation. Similarly, they will see the act of expanding a binomial expression such as $(2x + 3)(x - 5)$ as an instruction to carry out an operation rather than writing an equivalent expression. In both cases, students cling to long-established ways of working in mathematics that emphasise one answer, one method, and closure. Developing a deeper understanding of equivalence is therefore often troublesome for students but at the same time, opens up a gateway for seeing connections across mathematics.

Although there is evidence that students find estimation difficult, there is a more fundamental idea that is troublesome for students but that is essential for understanding any application of mathematics in the real world: accuracy. As described by Charles (2005), estimation with numbers or measures can be seen as a skill requiring facility with mental computation and familiarity with landmark referents. However, a more fundamental and troublesome idea is that no measure can ever be exact but rather that every measure has a built-in level of accuracy and uncertainty. Understanding that no measure can ever be exact conflicts with our use of the term exact in everyday language, while a failure to understand this leads to claims for accuracy that cannot be supported, and renders many scientific calculations at best inappropriate and at worst meaningless. Understanding the concept that no measure can ever be exact opens a view of mathematics that is challenging for students accustomed to a world of exactness, rightness, and wrongness, but also one that enables students to see the application of mathematics in real-world problems in a new light.

The importance of a focus on big ideas in school science education was recognised by the US National Science Teachers Association in their 1964 document *Theory into Action in Science Curriculum Development* (National Science Teachers Association Curriculum Committee, 1964). They recommended that the science curriculum development process start with the big picture of science rather than isolated facts or pieces of information. This would enable the development of conceptual schemes in order to present a comprehensive view of science.

The 14 big ideas for school science education developed at the PuRkwa Locj Lomond symposium (Harlen, 2010) were also seen as a way of addressing the disconnected nature of much school science education and the perceived irrelevance of the ideas learned in school science. The symposium advocated big ideas as a way of reconceiving science education as a progression towards an "understanding of events and phenomena of relevance to students' lives during and beyond the school years" (p. 2). The importance of challenging students' intuitive non-scientific ideas and of building on "small" ideas developed from studying particular topics to gradually form big ideas were recognised in the principles underpinning the selection of the big ideas.

Of the 14 big ideas, 10 described big ideas *of* science, while the remaining four described big ideas *about* science. One of the 10 big ideas of science was "All material in the Universe is made of very small particles". The symposium identified this as the basis for understanding states of matter, what happens when materials are combined, the internal structure of the atom, electricity, and radioactivity. However, the conceptual obstacles in developing an understanding of this big idea were not discussed and, as pointed out above in the study by Park and Light (2009) of the threshold concept of atomic structure, it is likely that many of the conceptions and implicit schema formed by students relating to this big idea prove obstacles in coming to understand matter at a submicroscopic level.

In one of the few papers contrasting big ideas and threshold concepts, Talanquer (2015) suggested that big ideas "focus our attention on learning targets and outcomes" while threshold concepts emphasise "the importance of students embarking on journeys that transform their ways of thinking in highly productive manners within a domain" (p. 3). Such journeys do not only involve putting together a collection of concepts to form a bigger concept—they are likely to involve setting aside or dismantling existing assumptions or concepts. Talanquer identified five specific conceptual schemas that underpin understanding related to threshold concepts in chemistry such as atomic structure. These were

1. *Moving from an additive property to an emergent property*. Applying an additive property to chemistry results in misconceptions such as thinking of substances as homogeneous aggregates of constituent substances, with their properties being the weighted average of those of the constituents. In this way, students treat the system as a composite static object rather than as a dynamic collection of interacting particles with properties emerging from the likely outcome of a very large number of such interactions.
2. *Moving from a centralised causal process to an emergent process*. A centralised process schema attributes cause and effect to active agents inherent in the substance, such as oxygen atoms always gaining electrons when reacting in order to obtain a full shell. Such causal processes are seen as linear chains of events which happen in order to fulfil some desired goal state. By contrast, an emergent process schema attributes observable patterns at the macro level to continuous and dynamic random interactions of submicroscopic particles, the outcomes of which are determined by internal or external constraints that affect the probabilities of particles interacting in particular ways.
3. *Moving from a homogeneous population to a varied population*. While novice learners view the world as consisting of submicroscopic particles that are homogeneous and invariable, experts recognise the central role of variability, not only in the properties of individual particles but also how this variability impacts on the behaviour of the system as a whole.
4. *Moving from an intrinsic property schema to an extrinsic property schema*. Whereas an intrinsic property schema sees chemical properties of a substance as absolute quantities possessed by the substance in all situations, an external property schema recognises that the properties of a substance depend on the environment in which the substance is placed.
5. *Moving from a variation to a conservation schema*. Novice learners tend to focus on how things change, seeking explanations based on what is different before or after an event. By contrast, the theoretical schemas devised by chemists often rely on what is conserved during a process to find relationships and build predictive models.

While big ideas help to provide a curriculum focus in both school mathematics and science, there is an implicit and sometimes explicit assumption that students develop understanding over time from experiences with numerous smaller ideas or instantiations of these big ideas. The literature on threshold concepts provides an important caveat to such an assumption by highlighting the conceptual obstacles that might result, not only from students' implicit schemas but even from well-intentioned but potentially misleading teaching. To cite two examples discussed above: in the case of school chemistry, the representation of the submicroscopic world in terms of macroscopic models may lead to significant obstacles in gaining a fuller understanding of the nature of matter, and; in the case of school mathematics, the overgeneralisation of finite process to infinite processes may lead to significant obstacles in understanding important ideas associated with limits and the calculus. The epistemological and ontological obstacles encountered in threshold concepts may even extend beyond these examples and impact on the student's conception of mathematics or science as a whole.

The next section describes a process that endeavours to identify threshold concepts that span mathematics and science that relate to the conceptual obstacles discussed above.

13.4 Methodology—Content Analysis of Two Australian Resources

Selected units from two contemporary Australian resources were used as data sources for content analysis (Krippendorf, 2004) with the intent of identifying threshold concepts that potentially span science and mathematics in the primary years.

Primary Connections: Linking Science with Literacy (Australian Academy of Science, 2019a) is an Australian Government funded project managed and conducted by the Australian Academy of Science. Its primary aim is as a professional learning program for primary science teachers supported by exemplary curriculum resources to enhance teaching science and literacy. It uses the 5Es teaching and learning model: Engage, Explore, Explain, Elaborate, and Evaluate, to structure each of the 41 curriculum units. There is at least one unit at each year level dealing with each of the major branches of school science: physical sciences, earth and space, chemical sciences, and biological sciences.

reSolve: Mathematics by Inquiry (Australian Academy of Science, 2019b) is also an Australian Government funded project managed by the Australian Academy of Science in collaboration with the Australian Associations of Mathematics Teachers. It comprises professional learning and teaching resources underpinned by the reSolve Protocol, an overarching vision for excellence in teaching and learning mathematics, and a cohort of 240 Champions charged with developing communities of inquiry around reSolve. It has 102 exemplary teaching resources, covering each of the content strands of the Australian Curriculum Mathematics: number and algebra, statistics and probability, and measurement and geometry, with at least one resource in each strand at each year level.

Units published in Primary Connections and reSolve (Australian Academy of Science, 2019a, 2019b) are intended to be coherent and cohesive documents that provide advice to teachers about what is important in the learning of particular topics in primary science and mathematics. While they provide general pedagogic advice, they have a particular focus on pedagogical content knowledge (Shulman, 1986) related to students' development of deep understanding of concepts in the specific content area being discussed. As such, they can be expected to provide insights into the extent to which the scientific or mathematical ideas are likely to be troublesome, transformative, integrative, and irreversible for students. The texts were, therefore, read through this lens, seeking to identify threshold concepts that might impact students' development of deep understanding but that might not be explicitly stated in the text. The analysis was thus much more than a literal review of the resources and the advice to teachers—the intent was to infer from the texts those aspects of the concepts being developed that would suggest underlying threshold concepts.

To identify threshold concepts likely to be encountered by students in the primary years of schooling that relate to the epistemological obstacles encountered by undergraduate students in their learning of atomic structure or limits described above, the Primary Connections chemical sciences units at each of years Foundation and 6 and the reSolve resources dealing with attributes or variation at each of Years Foundation and 6 were selected as data sources for content analysis. The two levels were chosen as the beginning and end of primary school education, thus affording the possibility of identifying critical changes in the concepts themselves and potential epistemological obstacles across the primary years. Each unit was read in detail with a view to identify a concept that cut across mathematics and science and that might satisfy at least some of the aspects of threshold concepts described in the literature. The concepts were identified both from the guidance for teachers outlining the big ideas in each resource and from a detailed examination of the recommended student activities. Four questions were asked of each potential threshold concept:

1. Is the concept likely to be troublesome now or into the future?
2. Is the concept likely to be transformative in changing how students view the world or approach science and mathematics?
3. Is the concept likely to be integrative, contributing to a more holistic view of the world, science, or mathematics?
4. Is the concept likely to be irreversible, providing a way of viewing the world, science, or mathematics that is unlikely to be forgotten?

As discussed above, the bounded nature of threshold concepts was omitted from the analysis as it was considered unlikely that any concept encountered by students of this age would push new boundaries in the discipline.

13.5 Analysis and Discussion—Identifying Some Threshold Concepts

13.5.1 Foundation Units

That's My Hat is a Foundation level Primary Connections unit that addresses the Australian Curriculum Science content description ACSSU003 "Objects are made of materials that have observable properties" (Australian Curriculum, Assessment and Reporting Authority, 2019b). It is intended that students explore the diverse nature of the world around them using their senses to observe the properties of materials. Explicit attention is paid to the distinction between an object and the materials from which it is made and to the importance of not automatically attributing the properties of the material to the object itself. The concepts are developed through the context of the decorations on a party hat, with students identifying materials with a range of properties such as softness, shininess, water resistance, or transparency.

Students start by describing the look and feel of objects in a "feely bag", sorting them on the basis of the observed properties. They then examine what happens when materials are exposed to water or sun to decide if they would be suitable materials for a hat that could be worn on a rainy or sunny day. They make predictions about whether a given hat will be waterproof, sunproof, both, or neither, with one hat constructed of aluminium foil but designed in such a way that the brim will allow both sun and water to pass through. Students design their own hat to satisfy some properties they select and explain their choice and design to others.

Attribute Train and *Shoes* are Foundation level reSolve resources that address the Australian Curriculum Mathematics content descriptions ACMNA005 "Sort and classify familiar objects and explain the basis for these classifications. Copy, continue, and create patterns with objects and drawings" (Australian Curriculum, Assessment and Reporting Authority, 2019a). The rationale for Attribute Train emphasises the importance of focusing students' attention on attributes and of using appropriate language to describe how shapes are the same and how they are different. The rationale for Shoes highlights the importance of recognising, describing, and representing variation in data through meaningful contexts.

In Attribute Train, students are asked to intentionally vary either the shape or colour shown on a card, but not both, to create a "train" that is as long as possible and a "circular train" that starts and ends with a blue square. The attribute of size is then added, and students vary one attribute at a time to play a strategy game trying to use all their cards. In Shoes, students gather and represent data on the shoes they are wearing to school, choosing some categories into which they might place them based on properties such as colour or how they are fastened. Students discuss questions such as how they might classify shoes that seem to span categories, why the number of shoes varies between categories, and how this variation might be different if we looked at shoes worn by older students or shoes worn at a different time of year.

In both the Primary Connections and reSolve resources (Australian Academy of Science, 2019a, 2019b), there is explicit emphasis on the identification and description of properties or attributes, and on the use of these properties to make predictions. Although not written as such in either set of resources, this big idea could be described as "Every object has a variety of different properties or attributes that can be classified and used to make predictions. The properties of an object are not necessarily the same as the properties of the materials from which it is made."

This is a threshold concept spanning mathematics and science.

1. It is *troublesome* in that students will often find it difficult to focus on one attribute in mathematics, or will attribute properties of materials to properties of objects made from those materials in science.
2. The concept is *transformative* in that students are introduced to a new way of looking at the world; that is, in terms of properties or attributes rather than function. A hat serves a function, but how well it serves that function depends on its properties, which in turn is related to, but not totally dependent on, the properties of the materials from which it is constituted.
3. For similar reasons, the concept is *irreversible* in that students are unlikely to base future discussion of how objects behave or of mathematical concepts such as area or angle on objects or shapes as a whole without consideration of constituent materials or parts.
4. The concept is *integrative* in that it helps bring together what students observe about objects in the world with knowledge of the properties of materials that make up those objects.

13.5.2 Year 6 Units

Change Detectives is a Year 6 Primary Connections unit that addresses the Australian Curriculum Science Understanding content description ACSSU095 "Changes to materials can be reversible, such as melting, freezing, evaporating; or irreversible, such as burning or rusting." The unit introduces physical and chemical change, with students investigating processes such as melting and evaporation, dissolution, and chemical reaction by modelling what happens at the particle level. The background information for teachers recognises the importance of addressing possible misconceptions, such as that substances which evaporate simply disappear, that heat and cold are substances involved in changes or that the total mass of substances before and after a chemical change varies.

Students start by examining some "mess scenes", consisting of stations such as melted chocolate, a perfume bottle tipped over, a glass full of bubbles from sodium bicarbonate and tartaric acid being combined, or a burning candle. They then look specifically at changes of state in terms of how the particles behave. They contrast the process of forming a solution with the process involved in a chemical reaction involving sodium bicarbonate and tartaric acid. They then look at the process of combustion, discussing the role of fuel, oxygen, and heat, by investigating what is needed to ignite a candle and to keep it alight. They conclude by classifying chemical and physical changes and conduct experiments in which the impact of external variables such as surface area or temperature is examined.

Rock, Paper, Scissors is a Year 6 reSolve resource that addresses the Australian Curriculum Mathematics content descriptions ACMNA144, 145 and 146 focusing on probabilities, relative or expected frequency, and the effect of large or small numbers of trials. The reflection on Rock, Paper, Scissors highlights the importance of randomness as a statistical concept stressing the difference between randomness in statistics and the colloquial use of the word random. It compares randomness generated with cards, dice, or a computer with the not-quite-random moves played by a person.

Students start by playing games of Rock, Paper, Scissors and justify why their chances of winning, losing, or drawing a particular game are each theoretically 1/3. They simulate playing a game using cards, dice, or a computer to develop the concept of randomness. They then consider that the moves made by a human are not truly random but include a psychological element. They look at and test a recommended strategy for winning that takes into account the psychology of the other player. The game is then extended to five possible moves and students investigate how people are influenced by prior results.

What connects the Primary Connections and reSolve resources is an explicit emphasis on small-scale variation and large-scale regularity. In Change Detectives, students act as particles and are randomly tapped on the shoulder to start moving more vigorously. At a large scale, the aggregation of particle behaviour models a change of state, first from a solid then to a liquid and then a gas. In Rock, Paper, Scissors, students discuss how randomness renders prediction impossible at a small scale yet the aggregation of results at a large scale makes long-term predictions within certain bounds of uncertainty possible. Students examine a winning strategy developed from extensive observation of players' psychology. This does not guarantee a win in every game but is likely to result in more wins than losses in the long term. Although not written as such in either set of resources, this big idea could be described as "Small-scale variability is inherent in the world and cannot be predicted with certainty. Events at a small scale accumulate to produce observable and predictable events at a large scale."

This is a threshold concept spanning mathematics and science.

1. It is *troublesome* in that, as discussed by Talanquer (2015), students will often attribute what they observe at a large scale to how particles behave at a small scale. Students assert that particles of a solid are themselves solid, or if an object is blue, its particles are blue. As discussed by Scheja and Pettersson (2010), students in mathematics inappropriately apply what they know about finite processes to infinitesimally small contexts involved in limits.
2. The concept is *transformative* in that students are introduced to a new way of looking at the world; that is, in terms of randomness and regularity. It is impossible to predict the outcome of individual events such as the roll of a die, but it is

possible to predict the relative frequency of each possible outcome over a long time. Similarly, it is not possible to predict how an individual particle will behave, but it is possible to predict how the substance made of those particles will behave.

3. The concept is *irreversible* in that students are likely to look more closely at large-scale trends or behaviour and ask questions about the small-scale events from which they are constituted.
4. The concept is *integrative* in that it enables students to construct explanations and predictions about large-scale events from consideration of small-scale behaviour.

13.6 Discussion and Conclusions

This chapter has looked at the nature of knowledge in STEM education. While there is considerable discussion about how a focus on big ideas can help to connect school level STEM concepts and develop a more holistic picture of science and mathematics, there is relatively little discussion of the epistemological obstacles that might be encountered in understanding these big ideas. Furthermore, the discussion of big ideas has focused primarily on big ideas *within* science or mathematics, rather than ideas that *span* science and mathematics. The research into threshold concepts, to date focused mostly on teaching and learning in higher education, helps to provide a lens through which such obstacles can be examined.

This chapter has proposed two such concepts based on a close reading of curriculum resources in primary science and mathematics:

- Every object has a variety of different properties or attributes that can be classified and used to make predictions. The properties of an object are not necessarily the same as the properties of the materials from which it is made; and
- Small-scale variability is inherent in the world and cannot be predicted with certainty. Events at a small scale accumulate to produce observable and predictable events at a large scale.

These concepts are not described explicitly in the resources themselves but are implicitly assumed in the student activities and advice to teachers. Each of these concepts is troublesome for students at the level at which they first encounter them, but potentially remain troublesome in the future. The concepts are transformative in changing how students view the world, irreversible in that once viewed in this way students are unlikely to cling to former ways of seeing the world, and integrative in that they bring together a range of concepts into a more coherent whole.

The concepts proposed are, of course, merely a start. The beginning and end of the primary years were chosen in order to show that threshold concepts can span levels of schooling. The way in which these concepts might change through the primary years or into the secondary years has not been traced, but there is significant research suggesting that related concepts prove troublesome in higher education. Having an awareness of the troublesome nature of knowledge encountered in higher education helps to inform the identification of the threshold concepts encountered by students in school; in turn, explicit attention to developing student understanding of these threshold concepts in the early years of school might help address the misconceptions underlying students' understanding of more advanced topics.

The resources used in the analysis are a very small fraction of the possibilities from which decisions might have been made. They were chosen because of their relatively close connection to threshold concepts encountered by higher education students described in the literature. However, the analysis points to the potential value in looking across science and mathematics resources to identify underlying commonalities. Further work will not identify a complete or comprehensive list of threshold concepts in STEM education, however, the process of identifying such concepts might prove informative for the research community, for educational designers and ultimately for teachers. For the research community, the identification and articulation of threshold concepts raises empirical questions relating to the degree to which what have traditionally called big ideas are, indeed, troublesome, transformative, integrative, and irreversible. For educational designers, the identification of threshold concepts raises new design challenges that open new and previously inaccessible ways of thinking for students. For teachers being aware of the troublesome aspects of threshold concepts allows them to pay explicit attention to the issues faced by students, being aware of the transformative aspects of threshold concepts opens possibilities for challenging students to expand the boundaries of their understanding, and being aware of the integrative nature of threshold concepts encourages teachers to promote more holistic approaches to STEM education.

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Chapter 14
Pedagogical Partnerships in Primary and Secondary STEM Education

Lena Danaia and Steve Murphy

Abstract It is crucial to provide students with a strong grounding in STEM education to continue to advance and contribute to the technological world. Many students develop negative attitudes toward school-focused STEM subjects, particularly science and mathematics, and often become disenchanted with these subjects as they progress through the compulsory years of school. The way in which these subjects are taught has been identified as a key element in engaging students. In the primary school context, many teachers have limited specialised knowledge in STEM areas and often lack confidence in teaching some of the content they are expected to teach while in the secondary school context, teachers typically have strong content knowledge but do not necessarily employ effective teaching strategies or represent the content in abstract ways and often fail to make cross-curricular links. This chapter reports on a novel approach to STEM education professional learning, used as part of a school-based research project. The approach brought together primary and secondary school teachers to collaboratively program and team-teach science, resulting in reported improvements in the content knowledge and self-efficacy for the primary school teachers, and enhanced pedagogical knowledge for the secondary school teachers.

14.1 Introduction

Science, Technology, Engineering and Mathematics (STEM) education is viewed as essential for a sustainable and prosperous future. Nations turn to science to meet the threats to our environment, the health demands of an aging population, and to ensure the security of our food, water and power supplies (UNESCO, 2017). Further, a scientifically literate citizenry is seen as key for a strong economy

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(Marginson, Tytler, Freeman, & Roberts, 2013). Australian policymakers and business groups share this perspective, vigorously promoting STEM education as a way to ensure Australia's security and international competitiveness (Australian Industry Group, 2015; Department of the Prime Minister and Cabinet, 2015; Office of the Chief Scientist, 2013). Australia's various jurisdictions have responded by initiating an array of STEM strategies with the aim to improve student engagement and achievement in STEM education, including science education (Murphy, MacDonald, Danaia, & Wang, 2018). Both the generalist and specialist teachers of STEM are key in implementing such strategies and initiatives.

To engage and improve students' academic performance in STEM, confident teachers who have the discipline knowledge, skills and who are capable of implementing engaging pedagogies are needed. Most countries require both primary and lower secondary teachers to hold a similar tertiary qualification. The key difference between the qualifications is that primary teachers' education tends to have a larger component that is focused on pedagogical and practical training while lower secondary teachers' tertiary education tends to have a larger discipline focus. This may result in primary teachers with poor knowledge of the content they are required to teach, and lower secondary teachers' with inadequate pedagogical expertise to effectively teach the disciplinary knowledge (OECD, 2018).

The purpose of this chapter is to share findings from a 2-year Australian school-based research project that teamed primary teachers with specialist secondary science teachers for the programming and teaching of science. The project aimed to build the primary teachers' confidence and competence in teaching science and hoped to extend the secondary teachers' pedagogical skills. This chapter describes the collaborative programming and team teaching approaches adopted and highlights the impact the project has had on both the primary and secondary teachers' pedagogical content knowledge. The discussion reflects on how the programming and teaching approaches adopted in this science-focused project could easily be translated to the individual discipline areas of STEM or STEM as an integrated approach. Implications for the professional development of teachers of STEM are also considered.

14.2 Australian Context

In many countries, primary school teachers are reluctant science teachers, and this is often attributed to low self-confidence in science teaching and scientific knowledge (Appleton, 2008). Australian primary school teachers report a similar lack of confidence with science teaching (Aubusson et al., 2015; Burke et al., 2016), and, compared to other nations, Australian primary school teachers are less likely to have a qualification with a major in Science or Mathematics (Marginson et al., 2013). Research has found that primary teachers with poor science knowledge and science teaching confidence, teach science less often and use more traditional teaching methods (Alake-Tuenter, Biemans, Tobi, & Mulder, 2013; Aubusson et al., 2015;

Tytler, 2007; Tytler, Osbourne, Williams, Tytler, & Cripps Clark, 2008). This may in part explain the 2015 TIMSS findings that Australian Year 4 students spend only 57 h a year studying science, compared to an international average of 76 h, and only 22% of teachers emphasised scientific investigation in the majority of their science lessons (Thomson, Wernert, O'Grady, & Rodrigues, 2017).

This relatively poor state of Australian primary science education is exacerbated by the impact of inadequate resourcing and time for science education in Australian primary schools (Goodrum & Rennie, 2007; Thomson et al., 2017). Further, time to prepare for science teaching, and having access to adequate classroom time for science education, are commonly seen by teachers as significant barriers to effective science education (Burke et al., 2016). Goodrum and Rennie (2007) argue that appropriate resourcing, along with professional learning, is a requirement for improving primary school educators' science teaching capacity and confidence. So there seems to be a complex range of interacting factors resulting in science education not receiving the attention it requires in Australian primary schools (Albion & Spence, 2013). Access to appropriate resources coupled with competent, confident teachers capable of implementing engaging pedagogies are needed in order to engage students in school science.

Secondary science teaching in Australia fares better in terms of teacher content knowledge and resourcing, but still faces some deficits in science pedagogy. The 2015 TIMSS found that 84% of Year 8 students were taught by a teacher with a major in science, slightly higher than the proportion internationally (Thomson et al., 2017). Year 8 students spend 126 h per year studying science, compared to an average of 144 h per year across the countries studied. Only 10% of Australian Year 8 students were taught by teachers reporting moderate to severe resourcing problems, compared to an average of 23% internationally. Despite being better placed in terms of content expertise and resourcing, secondary teachers do not necessarily employ effective teaching strategies or represent the content in abstract ways and often fail to make cross-curricular links (Danaia, Fitzgerald, & McKinnon, 2013). It would seem that strong pedagogical content knowledge (PCK) is needed for the effective teaching of school science (Appleton, 2008; Houseal, Abd-El-Khalick, & Destefano, 2014).

14.3 Pedagogical Content Knowledge

The construct Pedagogical Content Knowledge (PCK), was first coined by Shulman (1986), who defined it as

> … the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations — in a word, the most useful ways of representing and formulating the subject that make it comprehensible to others … Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics

> and lessons … that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding. (p. 9)

In essence, the construct PCK is a model of teacher knowledge (Grossman, 1990). The knowledge base is something that teachers develop over time and comprises much more than just knowing and delivering the subject content to students. Cochran, King, and DeRuiter (1991) defined PCK as “the manner in which teachers relate their pedagogical knowledge to their subject matter knowledge in the school context, for the teaching of specific students” (p. 1). PCK encompasses the following components: knowledge of students and their conceptions; knowledge and beliefs about purpose; knowledge about the curriculum; knowledge of content; and, knowledge of appropriate teaching strategies (Shulman, 1986; van Driel, Verloop, & de Vos, 1998).

PCK is essential for effective teaching and learning to occur. This requires teachers to be well adept at all of the components of PCK in their teaching. An effective teacher of science with high PCK would be experienced in moving through the various components of PCK and would make changes to their teaching based on their PCK to cater for the needs of their students. Abell (2007) presented a model of PCK for teaching science. In this model, Science Subject Matter Knowledge (comprising science syntactic and substantive knowledge), Pedagogical Knowledge (comprising curriculum instruction, educational aims, classroom management) and Knowledge of Context (comprising knowledge of students, the school and the wider school community) were three key elements that were identified as essential for effective PCK in teaching science. The model highlighted the interrelated nature of the components of PCK and explored how these elements interacted. One could assume that primary teachers would have strong pedagogical knowledge based on their tertiary training while lower secondary science teachers would be more inclined to have much broader and deeper science subject matter knowledge. One would anticipate that both primary and secondary teachers would both have knowledge of context. Given the importance of teachers having all of the elements of PCK for the successful teaching of science, it would be interesting to examine how primary and junior secondary teachers of science could work together to strengthen all of the elements of their PCK.

14.4 Collegiate Professional Learning in Science Education

Teacher collaboration and mentoring are potentially valuable contributors to improving science teacher capabilities. Opportunities for collegiate collaboration and participation in effective science teaching practices can contribute to building teacher self-efficacy and pedagogical content knowledge in science education (Mansfield & Woods-Mcconney, 2012). Conversely, a lack of time and opportunities to collaboration with colleagues is seen by primary school teachers as a significant impediment to effective science teaching (Burke et al., 2016). Mentoring is one form of collaboration suited to the development of improving the practice of science teachers (Bradbury, 2010). Mentoring between teachers has also been shown to contribute to teacher confidence and science pedagogical knowledge (Forbes & Skamp, 2016; Koch & Appleton, 2007). Forbes and Skamp (2016) investigate a mentoring arrangement not prominent in research, where secondary school science teachers mentor primary school teachers as part of the *MyScience* program. The findings of this research suggest that these mentoring relationships can positively impact on the beliefs and practices of mentor and mentee (Forbes & Skamp, 2014, 2016). The primary school teachers reported a changed understanding of what science education looks like in a primary classroom, as well as increased adoption of student-centred inquiry pedagogies (Forbes & Skamp, 2014). Similarly, the secondary science teachers involved in the project reported trialling more student-centred approaches with their Year 8 students, as well as developing a deeper understanding of the primary education context that then informed their work with Year 7 students (Forbes & Skamp, 2016).

Collaboration can extend beyond mentoring to include co-teaching. Effective co-teaching involves shared preparation, instruction, assessment and reflection, and requires strong communication and conflict management skills (Brown, Howerter, & Morgan, 2013). McDuffie, Scruggs, and Mastropieri (2007) conducted a review of 32 qualitative studies of co-teaching finding that teachers and administrators alike view co-teaching positively, with perceived academic benefits for students and professional benefits for teachers. Co-teaching may take several forms, including teach and assist (one teacher leads instruction while the other assists students as required); station teaching (teachers take responsibility for delivering different parts of the instructional content); parallel teaching (teachers divide the class and deliver the same instructional content); alternative teaching (one teacher instructs most of the class while the other withdraws a small group for support or extension); and team teaching (teachers collaborate to deliver the instructional content together) (Lusk, Sayman, Zolkoski, Carrero, & Chui, 2016). Research suggests that the 'teach and assist' model of co-teaching is most common, with 'team teaching' occurring least often (Pancsofar & Petroff, 2016). This is despite team teaching being viewed as the most effective form of co-teaching (McDuffie et al., 2007). There is limited research on the impact of co-teaching in science education.

Research suggests that effective professional learning that builds science pedagogical knowledge and allows teachers to experience successful science instruction could help redress some of the current deficits in primary science education (Burke et al., 2016; Deehan, Danaia, & McKinnon, 2017; Mansfield & Woods-Mcconney, 2012). Mentoring arrangements between primary and secondary teachers is one promising, but under-researched mechanism for delivering this professional learning (Forbes & Skamp, 2014, 2016) where primary teachers may have stronger pedagogical knowledge and secondary teachers may have stronger content knowledge (OECD, 2018). There is potential to extend this mentoring arrangement to include co-teaching (Lusk et al., 2016). While there is evidence supporting the positive impact of co-teaching in general classrooms (McDuffie et al., 2007), there has been minimal research into the impact of co-teaching on science education.

The school-based project examined in this chapter, informed by the aforementioned research, linked primary teachers with secondary science teachers for the programming and team teaching of primary science. The project aimed to build both primary and secondary teachers' PCK in the science curriculum area and in turn improved the primary teachers' confidence in teaching science and improve student outcomes and experiences in school science.

14.5 Context for This Research

The context for this research is a school-based science project implemented within a K-12 independent, coeducational day and boarding school. The school has over 1100 students and 305 staff. The primary and secondary departments are located on one campus but tend to work and operate in isolation from each other. Over the years, there had been very little, if any, opportunities for collaboration around programming and teaching. Before commencing the 2-year project, the primary teachers at the school indicated they lacked confidence in teaching the new national science curriculum and wanted professional development opportunities to help them teach investigative, inquiry-based primary school science. This became the stimulus for school-based collaborative programming and teaching of primary science project.

The project aimed to build primary teachers' confidence and competence in teaching inquiry-based school science by providing them with targeted specialist support and resources. Primary teachers were linked with specialist secondary science teachers for the programming and teaching of primary science. The teachers also had access to a science laboratory and specialised resources for the teaching of science. The secondary school science department had a focus on improving the instructional strategies employed to teach science in an attempt to try to make secondary science more engaging for students. It was anticipated that school-based project could also result in positive outcomes for the secondary science teachers involved. That is to say, by teaming-up the primary and secondary teachers, it was hoped that the primary teachers would help inform the secondary teachers of different instructional approaches and cooperative learning strategies that they tend to employ within their primary classrooms and which could be used and/or adapted for the secondary school context. Consequently, the research also investigated the impact of the project on the secondary science teachers involved. In particular, whether or not their involvement in the project informed or changed their practice of teaching science.

In the school-based project, students would be taught the Primary Connections curriculum materials designed by the Australian Academy of Science and which are mapped to the content of the National curriculum (Australian Academy of Science, 2019). The materials were supplemented with lessons that were constructed in the collaborative programming of the science content. It was anticipated that by having the primary and secondary teachers work together, it would hopefully ensure a developmentally appropriate continuum of learning in science within the school. The collaborative programming and team teaching approaches in implementing science were to be investigated to see what impact this had on student outcomes so that ultimately, improvements could be made to the way in which science was implemented and experienced at school. As part of the school-based project, students would be conducting experiments and practical experiences both within their classroom and within a science laboratory. The junior school had access to a science laboratory that is onsite (1-minute walk from their classroom). The location of where experiments and practical experiences were conducted was dependent on the lesson focus and content to be covered. The decision was up to the teachers implementing the experiences.

The purpose of the research underpinning the 2-year school-based project was to investigate the impact of these approaches on both teachers and students. There were three main research questions that were investigated within the larger project:

1. What impact does the collaborative team teaching and programming have on primary teachers' confidence and competence in teaching science?
2. What impact does the project have on the pedagogical approaches adopted by secondary school science teachers?
3. What impact does this approach have on students' knowledge outcomes and experiences in primary school science?

This chapter focuses on the impact of the approaches adopted on teachers' confidence and competence and on their pedagogical approaches in teaching science. The impact of the project on student outcomes (research question 3) will be the focus of a subsequent paper.

14.6 Research Design and Participants

A mixed methods approach was adopted for this research. Specifically, a Type-II Case Study (Yin, 2003) employing a pre-test/post-test design was used to investigate the impact of the project on teachers and their students. Questionnaires, semi-structured interviews, teacher programs, teacher reflections and student work samples were used to collect data from participants at different time intervals throughout the project (pre, during and post). This allowed comparisons to be made at different points in time across the project.

Within this research design, participating teachers also employed action research (McAteer, 2013) to reflect on the approaches they were using and to make changes to how they programmed, and team-taught future science units. In essence, results from the research coupled with information from teacher reflections were used to inform future cycles of implementation. The action research component was key in trying to ensure the sustainability of the project and in better informing future implementation through an iterative process.

A phased implementation approach was adopted to conduct this research project. This enabled the project to be introduced to different year levels and classes in different school terms. This allowed comparisons to be made between and within implementing and non-implementing classes to try to get a sense of the impact of the collaborative approach to programming and team teaching. It also provided a means by which to make the project scalable by gradually rolling it out across other classes.

The participants for this research comprised three groups: primary teachers; secondary science teachers; and primary school students. Over the 2-year period, 10 primary school teachers, three secondary school science teachers and 234 primary school students agreed to participate in the research. This paper focuses on the data collected from the 10 primary school teachers and three secondary school science teachers.

14.7 Collaborative Programming Days

Teachers were involved in a number of collaborative programming sessions that involved the primary teachers working in collaboration with the secondary science teachers. The collaborative programming sessions were held before the start of each school term. Primary and secondary science teachers were released from class and spent the day preparing the primary school program for the subsequent school term.

Over the course of the project, a total of eight professional learning programming days were held. As mentioned earlier, teachers would build their programs around the Primary Connections curriculum materials designed by the Australian Academy of Science (Australian Academy of Science, 2019). These units were already mapped to the National Science Curriculum and by using a 'base' unit, it allowed comparisons to be made with classes who were not involved in the team teaching approaches. During the programming sessions, the primary and secondary teachers spent time extending some of the lessons and/or modifying them to make them more inquiry focused and involve students in investigative science. The secondary teachers would examine each lesson in relation to the discipline content being explored and the primary teachers would share their insights into some of the pedagogical approaches that could be used with their primary students.

At each of these professional learning sessions, the academic mentor who was external to the school and who was responsible for conducting the research associated with the project was present. The academic would help facilitate some of the conversations between teachers. There were also opportunities for reflection built into these days. Where teachers were asked to reflect on what was working within the project, what could be improved and they were asked to share how they were feeling in relation to the project at that point in time. At some of the professional learning programming days, the academic reported on some of the student and teacher data that were collected within the project. This allowed teachers the opportunity to reflect on it and use it to inform the next wave of programming.

14.8 Data Collection Methods

Multiple quantitative and qualitative data sources were collected from participants over the 2 years of the project. Specifically, interviews were conducted with both students and teachers. Teachers also completed an online reflection and feedback form on two occasions while students completed questionnaires about their perceptions of science lessons at school. Students also completed pre and post-occasion questions related to the science content covered over the course of each school term. For the purpose of this chapter, the teacher interview data coupled with the teacher reflection data are used to highlight the impact of the collaborative programming and team teaching approach on teachers and their students. The student data will be the focus of a future paper.

14.8.1 Teacher Interviews

All interviews were semi-structured where there was a list of preprepared questions to guide the interviews. Teacher interviews were conducted in two different grouping situations that is, on an individual basis or in focus groups based on the composition of the teaching team. The length of teacher interviews ranged from approximately 20 to 30 min. All interviews were digitally recorded and were transcribed by a transcription agency. The interview data are used to gain insight into participants' thoughts and feelings about school science and to depict student and teacher perceptions of what was happening in science lessons during the project.

14.8.2 Teacher Reflections and Feedback

Teachers completed an online reflection and feedback form on two occasions. This form comprised the following questions:

1. What has worked for you in the collaborative science project (what have you liked)?
2. What has not worked for you in the collaborative science project (what have you disliked)?
3. What could be improved for you?
4. List three things you have learned during the project.
5. List three things you need to know more about.

The form was accessible via a survey monkey link and distributed to teachers during the final school term in the first year (2017) and during Term 3 of 2018. Teachers were asked to complete the form based on their experiences in the collaborative science project in each of the respective years.

14.9 Data Analysis

Thematic analysis was used for teacher interview and feedback data. Interview transcripts were read and coded for common themes within and across responses. NVivo (QSR, 2010) software was used to support the thematic analysis. Themes, counts and examples of responses are used to illustrate participants' thoughts and perceptions of what was happening in science during the project.

14.10 Teacher Results and Findings

The results below compare and contrast teacher perceptions and responses. The subheadings used represent the areas that were discussed in interviews or covered within the teacher refection and feedback forms. Where appropriate, direct comments from interview scripts and feedback forms are presented to illustrate teacher perceptions of, and experiences in, the project. The results shed light on the impact of the project on teachers' PCK in teaching science.

14.10.1 Things That Seemed to be Working

Collaboration was a key theme identified as something that was working well within the project. During the project, teachers collaborated on the programming of science units and in the teaching of them. The collaborative nature of this process is reflected in the following teacher quote: "*there was a lot of collaboration, so there was a lot of talking about "what if" and "could we do this" and "would that work*". In the 2017 interviews, four teachers made 10 references to how well-received the consultation and collaboration elements of the project had been while in 2018, four teachers made reference to the collaborative elements of the project that were working well for them.

Confidence and knowledge were two themes often used interchangeably within teacher interviews. It was evident across the 2017 and 2018 interviews that many of the primary teachers involved felt they had increased confidence in teaching science and that their knowledge and/or science vocabulary had improved as a consequence of working with the secondary science teacher in the project. The following quote from a primary teacher reflects how they felt the team teaching approach was helping to build their confidence in teaching science and their knowledge of content.

> For me, it's just like me feeling more confident. … I feel like I've learnt something and I am able to now confidently talk about heat and it being produced by certain sources and all of that sort of stuff. I feel the highlight for me is that I have grown so much this term and when I see the kids using the language that they're using… and not even necessarily just in science lessons. …It's really great to hear the language and see the understanding and the sorts of things that they're coming up with in science. That sort of excites me because you

think, oh, … they're actually … it's sinking in, whatever we've been teaching them. I would say that that's a highlight too.

Table 14.1 presents a selection of interview quotes from the primary teachers that related to improved confidence and/or competence in teaching science. In the 2017 interviews, six teachers made seven references to improve confidence and/or competence in teaching science while five teachers made seven references in the 2018 interviews.

Student engagement and enjoyment was also identified as an important theme under what was working within the project. In the 2017 interviews, five teachers made six references to student engagement and enjoyment while six teachers made five references to this theme within the 2018 interviews. The following quotes reflect the nature of this theme:

There's a definite interest in the children, you can see they're very focused on the task and the investigations and they're loving … I think they see themselves working as scientists.

I said the other day, there's no science today, and [sigh] so it was a negative response, which is a positive really.

There were some things that the kids just loved. I really find that, in general, the kids in year [class removed] still are really enjoying science.

Table 14.1 Confidence and improved knowledge example quotes from teacher interviews

2017 examples of quotes
I think my confidence with teaching the subject area. I'm really confident to pick up that material and know that I'm telling them, sort of scientifically I'm telling them the correct thing
I saw myself as being a bit hopeless with the whole science thing and just listening to the language and the vocabulary that they used was really helpful for me
I really like having [secondary science teacher] come into the room and hearing the sorts of the correct language or the vocabulary to use
I think that [secondary science teacher] enthusiasm for science has certainly got me a bit going, because really science wasn't something that I loved to teach, so I think that that's been useful
And the other thing is the language, the language that we're using, we're talking about chromatography, we're talking about heterogeneous and homogenous solutions and some mixtures
2018 examples of quotes
I'm certainly loving having [secondary science teacher]—that expertise, that real science knowledge, that's great. That's helping me, I feel, with questioning and working with the children
If you've got someone else coming into the room that can help explain that and that's their field of understanding, it helps you then understand
I think my confidence has definitely grown. I probably make sure that I fit the Science in, whereas before, prior to the project altogether, I may have gone, "Well, I can't fit that in so we won't actually do that this week"
I know for myself now I'm teaching science a lot better than what I was

In analysing teachers' responses to the feedback forms, comments were grouped based on the type of teacher participant involved (i.e. primary or secondary teacher). Consistent with the interview results, it was evident that the primary teachers felt the collaborative programming coupled with the team teaching aspect was invaluable. Having access to a discipline expert appeared to be worthwhile and beneficial for many as highlighted in the following primary teacher response: "*I liked team teaching with the Science high school teachers as they were able to give more scientific definitions and information. It also helped me to understand some of the content better.*"

Similarly, the secondary teachers felt the collaborative programming worked well within the project. Evident in some of the secondary teachers' responses was also an element of personal satisfaction that related to teaching the primary students. For example, "*Prep staff have helped me to understand progression from prep-high school.*" "*Programming was invaluable. Having the time to collaborate and plan together is the best part of this project, as we all learn from each other. By planning together, we all have buy in and understand where the program is going and what we are doing*."

14.10.2 Things That Were Not Working

Time was identified as a major theme across both teacher interview occasions and within the reflection and feedback forms. Teachers seemed to want more time to work on the collaborative programming before the start of a unit. It was also interesting to note that teachers wanted time at the end of a unit to be able to critically reflect on what had happened over the term and to allow them to make changes to the program for future implementation. The following three quotes illustrate the nature of this theme.

> More time to collaborate with the high school teachers.

> We went and printed the unit off and I remember looking at things, thinking, "Oh, no, that didn't work. We needed to change that," and we didn't have the opportunity to do that.

> More collaborative planning time and time built into review the data collected to be able to shape the direction of learning for different cohorts would be beneficial. Even time allocated to review units of work while they are fresh - to add in or take out activities would be helpful.

Timetabling was also a theme that was identified as a constraint or was of concern across the teacher interviews and within the feedback forms. The scheduling of science lessons within the primary school had to fit within the constraints of the secondary school timetable given some of the secondary science teachers were involved in the team teaching of lessons. The following quotes capture what teachers were saying in relation to this theme.

> I think the main thing that probably inhibits people is probably the flexibility with timetable.

> I think timetabling is a huge roadblock and the time allocated to be able to do this, so I guess it would be nice to see a little bit more importance placed on it.

14.10.3 Things Teachers Would like to See Continued

During the project, teachers' feedback helped inform the next iteration of the project. In the 2017 interviews with teachers, it was evident they wanted the collaborative programming to continue. Many of the primary and secondary teachers asked for additional time to be devoted to collaborative programming. This also seemed to be a top priority for respondents across the 2018 interviews. The majority of teachers in the 2018 interviews indicated that going forward, they wanted to see the collaborative programming continued and more time devoted to this before the start of a unit and at the end of a science unit to allow reflection and feedback to inform the next iteration of the unit of work.

The 2017 interviews revealed that two of the primary teachers and two secondary teachers involved in the project indicated that they would like better access to the science laboratories for their primary classes. There were two reasons offered for why these teachers wanted more access to the labs. First, they felt students would be *more excited* if they went to the labs. Second, the labs contain the equipment needed for lessons so there would be less time spent on sourcing and organising equipment. It is interesting to note that in the 2018 interviews, teachers did not mention the science laboratories as a priority going forward. Rather, their responses focused on the collaborative programming, extending the project to other year levels (continuum of learning—including the transition to high school) and continuing with aspects of the collaborative teaching.

14.10.4 Team Teaching Approaches

During the interviews, the teachers gave descriptions of their team teaching approaches. It was evident that there were different approaches used across the classes. There were some who appeared to work collaboratively together on all aspects and felt comfortable building on each other's ideas and approaches during lessons. This relationship seemed to develop and prosper over time.

> [Secondary teacher name] and I are very comfortable with each other so we just jump in and take off from wherever we left and I'm finding that easier and easier as it goes along but I'm also far more confident just to go, "Well hang on a minute, let's just come back a bit," or you know because sometimes [secondary teacher name] jumps in at a level that's a bit higher or sometimes even ask, "Where will we start?" and you know then I will say, "Now where are we going from here?" … So I'm finding the team teaching really, really good … The kids love it and we're able to split in the groups and both give really solid feedback to the kids.

There were those who highlighted the benefits their expertise brought to the lessons. Some of the primary teachers indicated they felt the secondary teachers helped with the content while they helped translate this content to an appropriate level for their primary students.

> It's just great having [secondary science teacher] there because he can pose questions and give information that I wouldn't necessarily have thought of, not being a science teacher.

> We really have bounced off each other in terms of the information that we both get I think in terms of delivering the lesson. I've sort of, in terms of talking with the kids and pitching it at their level, there's a few things that I've been able to bring to [secondary teacher name], so I talk about tools in the classroom.

Some of the secondary teachers indicated that the team teaching experience really made them stop and think about the purpose of their lessons. Some also felt there were things they could apply to their secondary science classes.

> It certainly makes you refocus on what the important point of the lesson is… It makes you stop and think about what's your main point in the lessons you're teaching up in senior school or are you just going all over the place that the kids in senior school can't connect the dots? … I think it's been really good because it actually makes you stop and think about how you explicitly instruct things, because I'm so much with senior kids you forget that you actually have to have a sequence of instructions.

A reflection from a participating secondary teacher indicated that their involvement in team teaching made them think about how they teach their secondary students. They have started to reconsider some of the scaffolding and pedagogical approaches that could be employed within their secondary science classes. The following quotes are from one of the secondary science teachers who was involved in team teaching.

> These kids were using, we were using words like homogeneous, heterogeneous, words like that, that when kids get to Year 7 we assume that they don't know. So that's been a real eye opener for me at the other end. We just kind of assumed that the kids get to Year 7 pretty much not knowing anything but … there is a fair bit that the kids do know, well from what I've seen at least at the primary level.

> I see a completely different angle to the kids and I think I just made assumptions about kids in primary schools without having ever really experienced it. And it's given me a few things to think about, and it kind of changes my approach to my Year 7 class … So I'm getting just as much out of it as [the primary teacher] is.

14.10.5 Things Teachers Had Learned

Teachers were also asked to reflect on things they had learned during the course of the project. It is interesting to note that many of the primary teachers commented on knowledge or competence related aspects that they felt they had learned. The following are some examples of the primary teacher responses for what they learned during the project: improved subject content; scientific knowledge base has increased;

new science vocabulary and terminology; better understanding of scientific diagrams; deeper knowledge of science outcomes; knowledge of using data for teaching has increased; ideas for practical activities; and, how to draw and annotate a science diagram.

Secondary teachers identified aspects that related to how they teach and would often make links with the secondary school context. The following are some examples of some of the secondary teachers' responses of what they learned during the project: ability to provide learning across faculties; teaching methods for prep kids; more of an idea of high school transition needs; persistence and behaviour management; and, importance of allocating time for programming.

14.11 Discussion

Similar to other countries, the Australian National Curriculum for all years of compulsory education requires inquiry-based science to be implemented. Many primary teachers often lack the content knowledge needed in order to teach the content of the science curriculum. This often results in them having a lack of confidence in teaching science. Secondary science teachers tend to possess strong content knowledge in their specialist area but often fail to implement effective teaching strategies. This chapter reported on a school-based research project that linked primary and secondary science teachers for the programming and teaching of primary science in an attempt to build the aforementioned areas of teachers' PCK in science.

The teacher interview results coupled with their reflections on the feedback forms suggest that the collaborative approach to team teaching and programming positively impacted their confidence and competence in teaching primary science. Many of the primary teachers reported that they felt they had increased confidence in teaching science and that their knowledge and use of science vocabulary had improved as a consequence of working with the secondary science teacher in the project. The collaborative programming and team teaching opportunities appeared to strengthen the primary teachers' knowledge of science content and equipped them with the necessary skills to develop and/or locate, modify and implement future inquiry-based science activities for their students. These findings are consistent with other literature (Forbes & Skamp, 2016; Houseal et al., 2014) where collaboration and mentoring between primary teachers and secondary teachers or primary teachers and scientists has contributed to increased confidence and science content knowledge for primary teachers.

The teacher interview results revealed that for some of the secondary teachers, involvement in the project made them reflect on the purpose of each science lesson they taught; both in the primary and secondary school context. Another also indicated they were planning to make some changes to how they would normally work with their Year 7 students as they were now aware of the content covered within primary school and how capable primary students were in learning science. These findings are consistent with others that have been reported in the literature where secondary teachers who have mentored primary teachers have reported having a deeper understanding of the primary education context that then informed their work with Year 7 students (Forbes & Skamp, 2016).

While there were some limitations to this research, the collaborative approach to programming, coupled with the team teaching of lessons, appeared to bring together the primary teachers' understanding of their students and various pedagogies and the secondary teachers' knowledge and skills in specific science discipline areas; two key elements of PCK needed for the successful teaching of science. Knowledge of content and knowledge of pedagogical approaches are key elements of PCK needed when teaching other STEM discipline areas. Thus, the approaches adopted within this school-based project could certainly be applied to Technology, Engineering, Mathematics and/or integrated STEM education. There is the potential for collaborative pedagogical partnerships to be formed within other STEM discipline areas.

Wheatley and Kellner-Rogers (2015) maintain that successful STEM learning environments require teachers to collaborate. They highlight the need to create collaborative communities of trust where teachers can take risks in their STEM teaching while learning together with other teachers. Strong relationships were formed between the primary teachers and secondary science teachers within this project. There was evidence to suggest that through the collaborative approach to programming and teaching, they learned alongside each other. The teachers continue to engage in professional dialogue about science and they are planning to continue this collaborative work in the future and possibly extending it to other curriculum areas. Given this project was set in the context of the primary school, more research is needed in the secondary school context to see how these secondary teachers translate some of what they have learned in this project into their secondary lessons.

The professional learning approach used in this project involved teachers working collaboratively together over a sustained period of time. They had the opportunity to model approaches and learn from each other in an ongoing capacity. Many of the elements contained within the professional learning approach adopted within this project are consistent with characteristics of other STEM professional learning models. Watson, Beswick, and Brown (2012) present a framework of professional learning for mathematics teachers. The framework comprised eight elements: teachers identifying issues; knowing learners and their characteristics; ownership by the participants; connected to the school context; sustained overtime; developing links between theory and practice through modelling; balancing individual and school community needs through collaborative participation; and, evaluation using student learning as an outcome. There are certainly parallels that could be drawn in relation to each of these eight elements and the characteristics of the school-based project described within the chapter.

The approaches adopted within the school-based project described within this chapter could be considered as a sustainable professional learning model for building teachers' PCK in STEM. There are very few similar examples of STEM professional learning for teachers represented in the literature, making combined use of mentoring and team teaching to build teacher capacity in STEM education. In this project, secondary and primary school teachers worked together to plan *and* deliver science programs for primary school students. In essence, a teacher community of practice (Wenger, 1998), centred on the programming and the teaching of primary science was created. The findings from this project suggest that this model builds content knowledge and self-efficacy in science for primary school teachers, while contributing to the pedagogical knowledge, particularly as it relates to student prior understanding and readiness, for secondary school teachers. Further, participants felt that the program had a positive impact on the quality of student learning in science in the primary school classes.

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Chapter 15
Transforming Pedagogy in Mathematics and Science in Qatar: A Study of Teacher and Student Perspectives

Nigel Calder, Carol Murphy, Nasser Mansour and Abdullah Abu-Tineh

Abstract Changes to teachers' pedagogy are complex, and frequently characterised by tensions evoked through teachers' experience and beliefs. As well, there can be entrenched cultural expectations. We are currently engaged in an international collaboration on a project, funded by the Qatar National Research Fund, to implement and evaluate Professional Development (PD) to promote Inquiry-Based Learning (IBL) in mathematics and science. The rationale for the PD programme is underpinned by Fullan and Langworthy's (A rich seam: how new pedagogies find deep learning. Pearson, London, UK, 2014) claims that new richer pedagogies can engage and motivate students, while more authentic ways of learning can be achieved through the use of digital technologies (Calder in Processing mathematics through digital technologies: the primary years. Sense Publishers, Rotterdam, The Netherlands, 2011), and through dialogic, collaborative group work (Mercer et al in Br Educ Res J 25(1):95–111, 1999). Eight Professional Development Specialists (PDS) in Qatar provide in-classroom support to sixteen teachers with grades 5–9 students. The PDSs have introduced WebQuests and Exploratory Talk as two practical manageable didactic strategies for the teachers. Data were collected from interviews with teachers and student focus groups, and from student questionnaires on attitudes to science and mathematics. Transforming teacher practice is not always straightforward. A key focus of the chapter is on the relationships between teachers' beliefs and perceived tensions in adopting the IBL and on students' perceived motivation and engagement. This chapter reports on teachers' and students' perceptions of the pre-PD data and

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situates this tentatively with the initial post-PD data. External influences and teachers and students' own internally held expectations impacted the introduction of IBL.

15.1 Introduction and Rationale

Internationally, there is a recognition that an innovative economy prospers through Science, Technology, Engineering, and Mathematics (STEM). This consensus is reflected in Qatar's National Vision 2030 (The General Secretariat for Development Planning, 2012), with an educational aim in Qatar to "strengthen K-12 and undergraduate programmes in the fundamental sciences and mathematics" (Qatar National Research Strategy, 2012, p. 2). Despite this aim, students in Qatar, as in many other nations, often become disengaged and disinterested in science and mathematics.

Negative attitudes towards science and mathematics have been recognised as a persistent problem internationally (Gluckman, 2011; White & Harrison, 2012). Mathematics and science are often seen as esoteric, uncreative, and difficult subjects (White & Harrison, 2012). This perception is often exacerbated by curricula and teaching that emphasise the acquisition of knowledge rather than understanding, often ignoring the relevance of STEM to students' lives. Research has suggested that IBL can overcome such negative attitudes (Anderson, 2007; Lederman et al., 2014; Maass & Artigue, 2013). For example, Hattie's (2009) meta-analysis suggested that:

> Overall, inquiry-based instruction was shown to produce transferable critical thinking skills as well as significant domain benefits, improved achievement and improved attitude towards the subject. (pp. 209–210)

The traditional approach to teaching in Qatar is primarily a transmissive teacher-directed model (BouJaoude, 2003) that emphasises the acquisition of knowledge. Whilst PD provided by external agencies has moved teaching practice in some schools towards IBL, this practice is not prevalent. Science and mathematics teaching often uses conventional pedagogical approaches with limited practical experiences and a reduced emphasis on critical thinking and inquiry-based activities (Said & Friesen, 2013).

Reviews have suggested that relying primarily on international organisations to deliver teacher professional development does not develop the capacity to reform teaching (Zellman et al., 2009). Furthermore, for professional development to work, it needs to be practical, classroom-based and manageable for the teachers. PD also needs to be sustained (Supovitz & Turner, 2000), with regular in-class support (Wee, Shepardson, Fast, & Harbor, 2007). Reflecting these various influential aspects, the PD for this project was devised in collaboration with The National Centre for Educator Development (NCED) at Qatar University (QU), alongside the national context of mathematics and science education in Qatar, and incorporating iterative feedback from students, teachers and PDSs. The PD was intended to be sustained, practical, classroom-based and delivered using a programme developed by the research team and the PDSs.

The overall research aim of our project was to investigate the potential of the PD to transform teacher practice towards IBL in science and mathematics. In this chapter, we predominantly report on the analysis from pre-PD interviews as an exploration of the teachers' and students' current experiences and their perspectives about the introduction of IBL into their classrooms and how these perceptions might influence their engagement with IBL.

15.2 Inquiry-Based Learning (IBL) in Science and Mathematics

Descriptions of what IBL means vary (Bybee, 2000). The different types of inquiry can be considered as a continuum from teacher-directed to student-centred pedagogy (Tafoya, Sunal, & Knecht's, 1980). At one end, there is minimal inquiry, where the teacher tells students the outcome of a problem and gives instructions on how to carry out an experiment or investigation in order to confirm the outcome. At the other end is an open-ended inquiry where students initiate both their own questions and their own processes to answer those questions. In between, processes such as guided inquiry are situated, where the teacher gives a prompt or question as a starting point, and the students develop their own process to answer the question, often with some negotiation with the teacher. Other interpretations of IBL variously describe teaching and learning approaches that include hands-on or project-based work as well as problem-based learning (Engeln, Mikelskis-Seifert, & Euler, 2014). In an inquiry-based design approach to science and mathematics education, Mooney and Laubach (2002) used open-ended problems set in adventure-based scenarios. They described their approach as inquiry-based and open-ended with one aim to engage the students in the engineering design experience. However, these approaches may not always reflect perspectives of IBL related to student-centred activities and the development of student thinking. Instead, they may equate IBL with hands-on practical experiences.

There are also differences in the interpretation and manifestation of IBL between science and mathematics. Science, as an empirical discipline, is generally seen to relate IBL to hypothesis testing and experimentation (Harlen, 2012). Teaching approaches may emphasise the carrying out of practical experiments rather than student-generated questions (Tang, Coffey, Elby, & Levin, 2009). The teacher poses a single question with one solution, and the students follow a process of collecting evidence and testing, but through teacher-directed discrete steps or instructions.

IBL in mathematics is less often associated with practical empirical activities. Instead, other activities such as questioning, exploring, conjecturing, explaining, reasoning, arguing and proving, representing and communicating are more often associated with a student-centred approach (Artigue & Blomhøj, 2013; Calleja, 2016; Swan, 2006). Even so, teaching may start with a problem or question, with the teacher providing a heuristic process for students to follow towards a predetermined solution, hence limiting exploration and questioning.

Conversely, IBL can become collective sensemaking within a context rather than the acquisition of content (Mansour & Wegerif, 2013) with the construction and reconstruction of knowledge between participants in specific contexts. Communication and sensemaking become key aspects of the interaction between teacher and student, and between students.

The view of IBL adopted for this project relates to a way of thinking through the posing of real questions and investigating tentative answers (Wells, 1999). Students are engaged in a search for "information, knowledge, or truth through questioning" (Chan, Lam, Yang, Mark, & Leung, 2010, p. 205), where the search refers to a student-centred activity that encourages higher-order critical thinking (Anderson, 2007).

15.3 Didactic Tools for Introducing IBL

In the PD reported on in this study, two didactic tools, WebQuests and Exploratory Talk, were introduced to provide practical classroom strategies to support teachers in developing IBL. The two tools were employed to help teachers encourage their students to raise questions, explore tentative answers, and communicate through collaborative group work. Two key elements were considered in selecting these tools. First, they were evidence-based tools shown to support IBL and collaborative talk between students. Second, that they would be practical and manageable for teachers within the timetabling constraints of their classrooms and curriculum expectations for both subjects.

Fullan and Langworthy (2014) suggested that the use of digital technologies can create new pedagogies that deepen learning and support authentic learning opportunities. Furthermore, Looi, Zhang, Chen, Seow, & Chia (2011) reported on a series of studies related to technology-enhanced inquiry science lessons that showed positive outcomes on student achievement and motivation, as well as reporting on the positive learning outcomes of their own project in primary science. Hence, the inclusion of WebQuests, as a particular use of digital technology, was intended to promote such positive outcomes in the PD in Qatar. WebQuests have been in use for well over a decade. Their use has been shown to inspire students to investigate and research answers to questions (Calder, 2011; McCoy, 2005; Salsovic, 2007). Originally devised by Dodge (1995) a WebQuest comprises six sections (introduction, task, process, resources, evaluation and conclusion). The introduction is presented as a problem or a "hook" for students to investigate either with questions set by the teacher or with students' own questions. While the sections provide a structure for students to follow, there is space for students to explore solutions authentically by researching on Websites, and to discuss tentative answers.

The notion of Exploratory Talk was developed both as a phenomenon, that is "a way of using language effectively for joint, explicit, collaborative reasoning" (Mercer et al., 1999, p. 97), and as a series of didactic strategies to encourage students to interact, interrogate issues, share ideas, clarify difference and construct new understandings (Mercer et al., 1999). The strategies included the development of key prompts to support students in investigating tentative answers, justifying their decisions and working towards a group agreement. Hence, the didactic strategies related to exploratory talk were employed as part of the PD to help the teachers encourage constructive dialogue and collaboration in student group work as they engaged with the WebQuests.

15.4 Tensions in Introducing IBL in Science and Mathematics

The PD intended that the use of the two didactic tools would enhance the teachers' acceptance of using IBL in their science and mathematics classrooms. The intention is to provide practical classroom strategies that would help both the teachers and their students to engage critically in asking and researching questions, to present tentative answers, and to engage in constructive dialogue to make and justify decisions. However, we could not assume that these didactic tools would be helpful in this context. Whilst resources and supported engagement are key elements in professional learning, teachers and students' existing practices and views also play a large role in determining how IBL is adopted (Anderson, 2002). In moving towards IBL, teachers no longer direct the process and steps for students. Instead, the teacher orchestrates and facilitates the learning processes (Calleja, 2016). Moving to these new practices may mean learning subtle skills, as well as challenging some teachers' views of effective teaching.

Grant and Hill (2006) identified challenge and stress factors that some teachers experienced when introducing IBL. One stress factor related to integrating student-centred learning within broader constraints from beyond the classroom. Teachers are influenced by the national context and their pedagogical approach is affected by the expectations and constraints of this system, for instance, at the society level (the role of science and mathematics in society and recent changes in education); school level (the organisation of the school system), pedagogy level (the traditions of types of pedagogy and the role of national assessment) and disciplinary level (place of inquiry in mathematics and science) (Dorier & García, 2013). Guidance and directives in many national curricula often suggest inquiry, creativity and problem-solving, but high-stakes external assessments primarily measure the reproduction of content knowledge. As well as this direct tension, teachers may feel that how well they can deliver content to students determines the quality of their teaching (Fullan & Langworthy, 2014). As a result, resistance to using IBL might be evoked by a range of sources external to teachers' own beliefs and capacities.

A second stress factor is the "recognition and acceptance of new roles and responsibilities on the part of teachers and learners" (Grant & Hill, 2006, p. 20). When a teacher directs the learning, the teacher also directs the dialogue and its focus (Foster, 2014). As the new roles and responsibilities evolve, there may be a sense that the teacher releases control and increases the responsibility of the learning towards the students.

This release of control also requires more "soft skills" by the teacher such as managing informal, flexible grouping structures. This leads to the third factor of comfort level—of both teachers and learners (Grant & Hill, 2006). An IBL context suggests that the teacher listens more and encourages students to ask questions and to examine possibilities and different solutions. With the increase in collaborative talk and small group work, there may be a consequential increase in talk and student movement around the classroom. The classroom environment may feel less controlled, disquieting and uncomfortable.

The fourth factor, "tolerance for ambiguity and flexibility" (Grant & Hill, 2006, p. 22), is a social and emotional factor. When teachers direct the learning, they are in command of the content being taught and can manipulate the learning directly around curriculum objectives. In IBL, the students find the knowledge themselves, and there is the potential for learning to move away from the anticipated content (Lipman, 2003). Teachers may feel there is a risk in tolerating such ambiguity in their classrooms, and students may feel unsettled when taking on learning from sources other than the teacher or textbook. The fifth factor relates to teachers' personal confidence in integrating technology. The teacher may feel they become an instructor of technology or a troubleshooter and will need to make decisions about how best to use technology. The teacher may no longer have command of the content and learning process, or feel that this impacts on their time for other curriculum content.

In summary, the introduction of IBL suggests the release of control and responsibility of learning from teacher to student. This shift has potential philosophical implications for teachers (Mansour, 2010). Teachers will have perceived, and actual, restrictions in managing the teaching environment, curriculum, timetabling, resources and teaching spaces.

IBL might also create challenges for students and, whilst some of this is desirable in relation to evoking students' thinking and learning (e.g. Calder, 2015) the multiple pathways and potential for making mistakes may be unsettling for some students (Gillies & Boyle, 2010). Not all students embrace the longer term aims of inquiry and tolerate the level of uncertainty involved. Those that do, endorse academic risk-taking and the re-evaluation of understanding through consultation of others, while others grapple with the increased ambiguity and flexibility (Grant & Hill, 2006).

15.5 Research Aims

For the larger project, our aim was to evaluate the ways that the two didactic tools supported transitions in teachers' practice with IBL in their mathematics and science classrooms. To better understand the teachers' decisions when introducing IBL, we needed to understand their initial perspectives. Many studies have explored teachers' attitudes following the implementation of IBL (e.g. Gillies & Boyle, 2010). Studies that explore experiences and beliefs prior to the implementation of IBL are less common. Engeln, Euler, and Maass (2013) carried out a large-scale baseline study of teachers' beliefs and practices across European countries prior to implementing IBL. They found a spectrum of views related to classroom management, systems restrictions and resources that could become factors in determining their adoption of IBL that related to differences in the cultures, practices and curricula of the different European countries. One question that arose was whether the teachers in the relatively homogenous Qatari culture held similar or diverse views.

There is a scarcity of research related to students' views and understanding of IBL (Lederman et al., 2014), in particular, students' perceptions and predispositions to the introduction of IBL. Yet a common understanding between teachers and students would seem important in introducing IBL while contrasting dispositions may cause tensions (Tang et al., 2009). Hence, we wondered if the students held similar or diverse views. The key research question reported on in this chapter is

- In what ways might the teachers' and students' current understandings and experiences of IBL influence their attitudes and approaches to learning through IBL?

15.6 Context and Design of the Study

The overall values and objectives in the Qatari education system aim to maintain an interaction between Qatar's cultural heritage and Islamic traditions, and other cultures and experiences, including scientific achievements and technological innovations. The Supreme Education Council (SEC) oversees education policy and the development and implementation of education reform and curriculum development, with the National Curriculum Standards setting the expected curriculum and attainment in key subject areas, including science and mathematics and the Qatar Comprehensive Educational Assessment (QCEA) (Ministry of Education and Higher Education Qatar, 2018). The standards are detailed indicators about the content skills and knowledge students should acquire in each grade, but schools and teachers have the freedom to design their own curricula, instructional strategies and lesson plans. Skills such as critical thinking, inquiry, and reasoning are emphasised in the science curriculum, and real-world problem solving is valued in the mathematics curriculum.

In this project, we worked with students from primary schools (grade 5) and from secondary preparatory schools (grades 7–9). Instruction in these schools is in Arabic. In both primary and preparatory schools, specialist teachers teach science and mathematics separately and science laboratory facilities are available to students. Computing facilities are concentrated in technology laboratories and there is little use of digital technologies in other classrooms. Each class has 20–25 students. Students received six–seven mathematics classes a week and four–five science classes a week, while textbooks are prescribed and used by the teachers to support curriculum teaching.

The data reported in this chapter is drawn from a larger three-year research project. The first year of the larger project involved eight teachers (four science teachers and four mathematics teachers) from four schools in an initial introduction of the PD. The second year involved sixteen teachers (eight science teachers) from eight schools. Eight PDSs (four specialists in mathematics and four specialists in science) worked with the teachers. During these two years, the PDSs presented initial workshops and provided in-class support at intervals across two school terms. The third year of the project involved the voluntary establishment of schools as learning centres for continued dissemination of practice. The data for the chapter is from the second year, when the main PD took place. The data were used to focus on comparing teacher and students' initial perceptions of IBL with their perceptions after engaging with WebQuests and exploratory talk activity. This engagement with the two didactic tools took place over a four-month period, with a variety of actual times depending on the school context. However, each teacher introduced at least two WebQuest topics over the four-month period. Science topics included: Healthy diets, acids and alkali, electrical circuits, the human skeleton, weather and erosion, while mathematics topics included decimals, percentages and ratios, areas and perimeters of shapes, angles, probability.

The sixteen teachers had a range of teaching experiences from two years to twenty-two years (Table 15.1). All the teachers had at least degree-level qualifications, either in the subject area they were teaching or in education with a specialisation in the subject. In presenting the results, pseudonyms have been used to maintain anonymity.

15.7 Methodology

The methodology of the larger three-year project was based on a transformational model of professional development (Leys & Bryan, 2001), where teachers make decisions on how to adapt pedagogical strategies in contexts that are relevant to their classrooms. In addition, a case study method was used, and a cross-case study analysis approach was taken using the principles of constant comparison technique (Strauss & Corbin, 1990), allowing comparative analysis of anticipated outcomes for each case. In this paper, we report on a cross-case study analysis of the sixteen teachers, eight science teachers and eight mathematics teachers, and their students involved in the second year of the project. They are viewed as four cases for analysis: science teachers, mathematics teachers, science students and mathematics students. The data consist of interviews with the sixteen teachers, and focus group interviews with their students, grades 5–9. Teachers were interviewed individually, and each student focus group had 6–10 students. Both the teacher and focus group interviews were carried out in Arabic. The interviewer took handwritten notes which were translated into English. The interviews were undertaken each year, with one in November (before the introduction) and then another in May (after the WebQuests). Each interview lasted approximately 30 min. All the responses were kept anonymous and confidential, and pseudonyms were used to refer to the teachers. Students' names were not used.

Table 15.1 Participant teachers

	Science teachers			Mathematics teachers		
School	Class	Teacher	Length of service; qualifications	Class	Teacher	Length of service; qualifications
1 (Prep)	Grade 7; boys	Alem	19 years; science/education graduate	Grade 8; boys	Irfan	11 years; mathematics/education graduate
2 (Primary)	Grade 5; girls	Bushra	8 years; science graduate	Grade 5; girls	Jena	2 years; education graduate
3 (Prep)	Grade 7; girls	Chaima	16 years; science/education graduate	Grade 7; girls	Katya	17 years; mathematics/education graduate
4 (Primary)	Grade 5; girls	Dina	13 years; science graduate	Grade 5; girls	Lina	22 years; science graduate/education diploma
5 (Primary)	Grade 5; girls	Esma	10 years; science graduate/education diploma	Grade 5; girls	Maya	5 years; science/mathematics graduate
6 (Primary)	Grade 5; girls	Farah	16 years; science graduate	Grade 5; girls	Nadia	4 years; mathematics graduate
7 (Prep)	Grade 7; boys	Gamar	18 years; science/education graduate	Grade 7; boys	Omar	15 years; mathematics and education graduate
8 (Prep)	Grade 9; girls	Hessa	12 Years; science graduate/education diploma	Grade 9; girls	Perla	4 years; mathematics graduate

Individual teacher interview questions were structured and based on the following topics: current understanding of inquiry and how this might relate to their current classroom practice; how well they felt their students could investigate and discuss ideas independently; if they felt that introducing IBL using WebQuests and Exploratory Talk would support students' learning and, if so, in what ways; if they had any concerns in introducing IBL using these tools and, if so, what might they be.

Student focus group interviews were also structured and based on similar topics: current understanding of inquiry; if they felt their teacher used inquiry when teaching either science or mathematics; how well they felt they could investigate and discuss ideas independently of their teacher; if they thought that IBL would help them learn science or mathematics and if so how. As the students were interviewed in focus groups, data were collected from the whole group, and the views presented in this report are not identifiable to specific students. Neither are the views representative of the whole group. Where differing views were evident in a group these have been presented.

Table 15.2 Categories and themes for analysing teacher and student focus group interviews

Categories	Themes
Current understanding and experiences of inquiry	Subject-based focus: scientific method or problem-solving Current experiences: Focus on process Current experiences: Focus on exploration and student learning
Aspirations regarding the introduction of inquiry	Constructing knowledge and deepening learning Attainment of knowledge Learning life-long skills Students' motivation, attitude, and engagement
Concerns regarding the introduction of inquiry	Students' learning Students' skills, abilities and dispositions Classroom environment and resourcing

Initial analysis of the teacher and student responses enabled different themes to emerge in relation to subject-based views (inquiry within science or mathematics) and focus of inquiry in teaching and learning (on process or on student exploration and thinking). Aspirations and concerns of both teachers and students were analysed in relation to emerging themes: students' learning and meeting objectives; students' skills, abilities and dispositions; classroom environment and resourcing. These themes are listed in Table 15.2.

A second set of data also informed our discussion, albeit to a more limited extent: the initial analysis of the attitudinal questionnaires given to the students. The attitudes towards mathematics questionnaire (Tapia & Marsh, 2004) and the attitudes towards science questionnaire (Kind, Jones, & Barmby, 2007) were also undertaken in November and May. Part of the initial analysis of these data were non-parametric statistical tests that were undertaken to determine if there was any change in the students' attitudes between the surveys completed prior to the IBL PD, and post the intervention. Reported in section four, it is also included in the summary of the findings and the conclusions of the chapter.

15.8 Results and Analysis

For each of the categories, teachers' and students' responses were coded according to the themes indicated in Table 15.2. These themes are presented in three sections:

1. Current understanding and experiences in inquiry,
2. Aspirations regarding the introduction of inquiry and
3. Concerns regarding the introduction of inquiry.

Each section is summarised. Following these three sections is an analysis of change in student attitudes and an overall summary. Examples of key phrases from the teachers and students are used to illustrate some of the key views related to each theme. Key points are summarised for each category in relation to teacher and student views for both subjects. There is also some initial analysis comparing the pre- and post-survey data with regards to student attitudes towards science and mathematics.

15.8.1 Current Understanding and Experiences of Inquiry

Teachers were asked about their understanding of IBL and how inquiry related to their current classroom practice.

15.8.1.1 Science Teachers

Science teachers predominantly referred to inquiry as a scientific method:

> Chaima: Inquiry is the main teaching in science. It depends on scientific observation, putting hypothesis, testing it and making a conclusion.

Nevertheless, some science teachers referred to a more exploratory approach:

> Hessa: We explore concepts in an authentic way.

However, it is still how unclear how much the teachers would tolerate a challenging situation that might promote a dialectic interplay. For example, Dina's comment that she would be less likely to use an open approach if the topic was new, suggested that she was not likely to provide such a challenge:

> Dina: Inquiry means that the learning takes certain skills to organise and manage knowledge and thereby generate knowledge through researching and asking questions. I may allow open inquiry. However, if the topic is entirely new for students, I prefer the directed type.

15.8.1.2 Mathematics Teachers

Two of the mathematics teachers also related inquiry to scientific method. However, when reflecting on their current experiences of inquiry in their classrooms, mathematics teachers tended to refer to problem-solving, including Lina who also related inquiry to scientific method:

> Lina: Students research in a scientific way and collect information then apply it in other situations. I put the student in a problem and give her an opportunity to discover a solution to the problem.

One mathematics teacher, Omar, referred to his experience of teaching inquiry in relation to processes that suggested statistical inquiry, but that these processes were carried out under his direction.

> Omar: Students collect, analyse, and explain data about certain topics, mainly under the direction of the teacher.

Such understandings suggest the doing of inquiry. The two mathematics teachers who referred to problem-solving, Katya and Lina, also related to the term discovery, indicating a student-centred approach, with the potential for dialectic interplay, and, hence, inquiry as a vehicle for learning.

15.8.1.3 Science Students

Science student responses suggested that they saw inquiry as the scientific method. In describing their own experiences of inquiry in science lessons, students referred to hands-on activities, experiments or laboratory work.

> (Inquiry is) Conducting experiments in science.

In addition, the students indicated that their teacher guided their work by giving instructions or explaining the steps.

> Inquiry is hands on activities; Our teacher guides us to work by giving us clear instructions; He does the inquiry for us.

Some indicated that they would be unable to carry out the work without these instructions.

> We use inquiry in labs and in working together in groups; We cannot do the inquiry without the teacher's help; He provides us with the information necessary to investigate.

Such responses reflect a teacher-directed approach where there was little opportunity for challenge or dialectic interplay. None of the students in the focus groups indicated that they engaged in inquiry in an exploratory way.

15.8.1.4 Mathematics Students

Mathematics students did not explicitly relate IBL to the subject of mathematics instead of referring to the scientific method and some students stated that inquiry or discovery did not happen in mathematics.

> There is no discovery in mathematics class, discovery is only in science.

In describing current experiences, several students in many of the groups suggested they followed processes to find answers.

> Teacher provides explanation and demonstration; She leads us to find answers; She provides clear instructions to follow and complete the task.

Statements such as “making the lesson easy” and “helping to find answers” suggested that their teachers attempted to minimise any challenges in finding the unknown.

15.8.1.5 Summary of Analysis of Teachers’ and Students’ Current Understanding and Experience of IBL

The most frequent perspective of IBL across all four cases (science teachers, mathematics teachers, science students and mathematics students) was related to the scientific method. Problem-solving was referred to by mathematics teachers and students when they described their experiences. Descriptions of current experiences often related to processes with teacher-directed experiences. There was some reference to using a more open approach by science teachers, but only where they felt there would not be too much challenge, or that it was only the higher achieving students who would cope with the challenge. Instead, there appeared to be a tendency not to make the learning too challenging for students, with some students stating that they needed the teacher to explain steps or to make the learning easy.

15.8.2 Aspirations Regarding the Introduction of Inquiry

15.8.2.1 Science Teachers

Generally, the science teachers’ responses have focussed around constructing and deepening learning although it is not so clear if this relates to lesson objectives or to the learning of facts rather than the understanding of concepts:

> Hessa: It meets the objectives of the lesson in an easy way and helps the students in remembering the different concepts.
>
> Busra: Information is further enhanced by students’ research and reflection. Students build scientific terms.

Some responses related to learning life-long skills such as critical thinking, becoming independent learners, and linking to life experiences:

> Alem: Inquiry develops critical thinking.
>
> Esma: Students become more independent learners to reach information.

Several science teachers also related IBL to affective aspects such as strengthening self-confidence and increasing participation and motivation.

> Dina: Motivates students to explore and to achieve pleasure during the process of gaining information and knowledge.

15.8.2.2 Mathematics Teachers

Most mathematics teachers referred to learning which suggested that the attainment of knowledge in relation to the correct use of facts and meeting the lesson objectives.

> Maya: Deepen understanding, building on previous experiences and then giving the new information.

References to thinking were less common but Irfan suggested that inquiry would support the organisation of thinking, not just in finding solutions but also in discovering new relations:

> Irfan: Using organized thinking to reach the right solution and discover new relations.

Several teachers' comments were made in relation to developing confidence and motivation:

> Jena: Enhances students' confidence.

15.8.2.3 Science Students

Science students used the term understanding but it is not so clear if they were referring to deeper understanding. However, one feature of their comments is that they related to the students' own responsibility for learning in relation to supporting understanding:

> We discover by ourselves and we become self-independent in the future.

Students' comments in relation to attaining knowledge indicated that their own actions would help them remember and clarify learning. One student also indicated that the dialogue with a friend would help her to remember.

> New information enters your brain easily and not go out; I remember my friend's face and the answers.

Several students referred to learning skills and how these would relate to their lives. The opportunity to be responsible for discovery would increase their independence in learning, with one student suggesting this as a potential skill for a career in science.

> We prefer to explore on our own because it helps us to learn better since science is related to our lives and when we study them we can explain how and why it happens; I want to learn how to depend on myself because when I am older I want to be a scientist.

Several groups of students also referred to increased motivation.

> Inquiry is more interesting and easy to understand.

15.8.2.4 Mathematics Students

Mathematics students' responses on the potential benefits of IBL, while a few, suggested that taking responsibility for finding results or for investigating would increase their understanding and help them to remember.

> Because we find the results by ourselves, we will be able to increase our understanding and we will not forget the whole learning process.

Comments in relation to motivation and engagement were more prevalent and it seems that some students felt they would be comfortable to take risks as the teacher would correct their work:

> We will be happy when we try to find the answer by ourselves even if it was the wrong answer because our teacher will correct our work.

15.8.2.5 Summary of Analysis of Teachers' and Students' Aspirations for Introducing IBL

References were made to enhanced learning in all four cases. Often teachers related learning to finding solutions and meeting lesson objectives, and students suggested that sharing ideas in inquiry would help get to an answer. Often the term information was used, suggesting acquiring facts and knowledge rather than deepening learning. Farah referred to making connections in science, suggesting deepening understanding rather than learning facts. Some students referred to increased understanding, but they also referred to remembering their learning.

References to skills were less prevalent in mathematics cases. Life-long skills were referred to more by teachers and students in science rather than mathematics. All four cases referred to the role of IBL in supporting motivation and engagement.

15.8.3 Concerns Regarding the Introduction of IBL

15.8.3.1 Science Teachers

Science teachers' comments in relation to students' learning tended to relate to meeting the curriculum or to a lack of teacher direction. There was also a sense of the teacher needing to be in command in meeting the learning objectives for the lesson:

> Dina: We already apply inquiry in science lessons, yet we do not depend totally on the students to work independently; we need to explain the lesson. I do not think students have the skills to conduct an inquiry independently due to lack of the required skills or their low academic performance.

Concerns about the ability of students to engage in constructive dialogue would also resonate with opportunities for students to learn through IBL:

> Esma: There are low achieving students who are not able to run a dialogue or bring new ideas so that they are listeners or just agree on what others say.

15.8.3.2 Mathematics Teachers

Several mathematics teachers expressed concerns related to covering the curriculum, student achievement and meeting needs:

> Irfan: Limitation of time and restricted by a certain amount of curriculum.

Maya suggested that this was more of a concern with lower achieving students:

> I have concerns about some of the less accomplished students and the impact on their academic achievement.

One mathematics teacher seemed concerned about behaviour management in the classroom and a possible lack of control as students worked together:

> Omar: There may be periods of difficulties such as a small number of students with behavioural difficulties restricting my work with other students.

15.8.3.3 Science Students

Responses from science students in relation to concerns about introducing IBL related to lack of teacher direction in supporting their learning.

> No, it will not help as it is not direct, and some students don't get it in an indirect way; I don't like it when the investigation is not clear enough.

Some referred to being uncomfortable either through shyness or lack of support within a group.

> I feel shy to share ideas; I do not feel comfortable to share ideas, they always say I am mistaken, they do not help me; There are a lot of students who do not like to participate in discussion.

15.8.3.4 Mathematics Students

Mathematics students' concerns about introducing IBL also related to lack of teacher direction in supporting their learning or lack of cooperation and constructive dialogue when working in groups.

> I don't feel comfortable because the responsibility will be ours. We prefer the explanation by the teacher.

> I don't like discussing ideas in math lessons because other students will confuse me. We feel that the teacher has the best ideas.

Some suggested that investigation was not the best way to learn mathematics and others were resistant to the responsibility this might give them. These concerns also related to dispositions such as discomfort, confusion, fear and embarrassment.

> Sometimes we are afraid that our answer will be wrong; I feel embarrassed when my answer is wrong.

15.8.3.5 Summary of Teachers' and Students' Concerns in Introducing IBL

Teachers in mathematics and science both expressed concerns related to meeting the curriculum, and mathematics teachers also expressed concerns about meeting the needs of their students. One science teacher, Dina, was concerned regarding her role in directing the learning and other science and mathematics teachers expressed concern that students did not have the skills or dispositions to take on the responsibility for learning in IBL.

Students' concerns often echoed those of the teachers in regard to directing the learning, taking responsibility and collaboration. Several students in both mathematics and science classrooms felt that a lack of teacher direction would impede their understanding or in getting the answer correct. Students also mentioned shyness, embarrassment and discomfort.

15.8.4 Analysis of Changes in Students' Attitudes Towards Mathematics and Science Post the IBL Intervention

One aspect of the data analysis involved the potential influence of using IBL on student attitudes towards mathematics and science. This was drawn from the analysis of the questionnaire data, which was also given prior and after the WebQuest work in the classes. For the students' attitudes towards science this included:

- Self-concept in science,
- Practical work in science,
- Science outside of school,
- Future participation in science,
- Importance of science.

While for the students' attitudes towards mathematics this included:

- Value of mathematics,
- Students' self-confidence,
- Enjoyment of mathematics.

Non-parametric statistical tests were undertaken to determine if there was any change in the students' attitudes between the surveys completed prior to the IBL PD, and post the intervention. The Wilcoxon Signed-Rank Test revealed a statistically significant improvement in the students' attitude towards both mathematics ($Z = 5.042$) and science ($Z = 5.283$).

Both teacher and student comments from the interview and questionnaire data also suggested some changes in attitudes and approaches to learning. For example, typical post-intervention teacher comments across both subjects were

> It assisted students in self-learning; find different sources of information; think critically; and explain their thinking.

Student comments identified similar aspects:

> We become more self-dependent, and learn to make searches on the Internet; it's very motivating; we can choose the peers to work within the group; it makes understanding easier.

One student was quite specific about the critical thinking skills that they perceived were enhanced:

> … (IBL helped) to make decisions, make judgments and justify them based on the right information.

However, this change cannot be directly attributed to the IBL intervention exclusively and there is a range of possible mitigating aspects, such as the potential of heightened positivity from the teachers through the intervention period. Nevertheless, it indicates attitudinal transitions and changes in learning. An in-depth analysis of the qualitative and quantitative data from the corresponding period will hopefully give further insights and finer grained analysis into these aspects. Once analysed, this will be reported in a subsequent paper.

15.8.5 Summary of Analysis

In general, both science and mathematics teachers saw the benefits of introducing IBL into their classrooms. Teachers considered that the introduction of IBL would increase students' motivation and engagement in learning and develop a more positive attitude towards mathematics and science. Teachers also aspired to using IBL to enhance learning, but these aspirations were often directed towards acquiring information, memorisation and meeting lesson objectives. In addition, some teachers articulated concerns that the student-centred nature of IBL would counteract learning, either through lack of direction by the teacher or problems with behaviour during independent group work. It seemed that some of the teachers aspired to IBL as an approach to motivate students, but not at the cost of losing direction and control of the teaching.

Several students indicated that IBL would help them enjoy learning and increase their interest in the subjects. Some students also aspired to become more independent in their learning and to develop skills for future education and careers. These views were contrasted by students who were concerned that they would not understand the content of the lesson, with some mathematics students stating they did not think inquiry would help them learn. For these students, taking responsibility for learning and investigating independently of the teacher seemed undesirable and risky. Interestingly, preliminary analysis of the student attitudinal data from the surveys indicated positive changes in their attitude towards learning in mathematics and science following the IBL work. Both teacher and student comments after the IBL learning were indicative of the perception that IBL encouraged student self-learning, motivation and critical thinking. Whether this influences the integration of IBL in practice, as well as students' and teachers' attitudes to IBL, needs further consideration over the next phase of the project, but at this stage, it appears reasonable to speculate that it might.

15.9 Discussion

In this discussion, we present a synthesis of the tensions that emerged between the aspirations and concerns of the participants and relate them to Grant and Hill's (2006) challenge and stress factors. We use this synthesis to indicate further how both external influences and teachers' and students' own internally held expectations might impact on the introduction of IBL using the two didactic tools.

Some of the teachers in this study made references to meeting lesson objectives and covering the curriculum. With these external realities, it is understandable that teachers feel accountable for their students' subject preparation (Fullan & Langworthy, 2014). They might feel that quality of teaching is judged by how well their students are prepared in reproducing the content, and not in how well they implement IBL. As such, teachers' aspirations for introducing IBL may well have reflected increased engagement and motivation but they also reflected the reproduction of content knowledge. Furthermore, teachers tended to equate IBL with the scientific method. Lederman et al. (2014) suggested that such views are not untypical, but how much these views are due to teachers' own internal expectations or how much they are externally influenced through curricular directives is less clear.

These understandings, coupled with the tradition of pedagogy, may go some way in explaining teachers' concerns in moving from a monologic approach of taking students from the unknown to the known with clear instructions. If the teachers' view of quality teaching is for students to reproduce subject content, then their students may also interpret quality teaching in this way. Such accounts were often supported by their students stating that their teacher gave clear directions in carrying out practical work and problem-solving.

However, not all teachers and students viewed quality teaching in this way. Whilst some science teachers indicated that their current practice was more teacher-directed they did aspire to a more student-centred pedagogy.

A view of the quality of teaching may also influence how prepared teachers and students are to take on new roles and responsibilities. If a teachers' view of quality teaching is to prepare students to reproduce subject content, then shifting responsibility to the students might imply not meeting students' learning needs in relation to the curriculum. Some students also had concerns in taking on new responsibilities for their learning with a preference for being guided in understanding the key ideas in a lesson. Some teachers were uncomfortable about a potential loss of control in managing group work within a more dynamic environment. They felt that their students lacked the skills, ability or creativity to work collaboratively and independently of the teacher. Gillies and Boyle (2010) have pointed out that these concerns can relate to teachers' lack of understanding in the use of this pedagogical practice in their classrooms, hence challenging their skills of class management and causing discomfort for themselves and their students. These findings resonate with those that Engeln, Euler et al. (2013) reported, indicating that teachers' perceptions of changes in classroom management and systems appeared to influence the transition to IBL.

Another level of discomfort appeared in relation to ambiguity and flexibility. Some teachers were concerned that their students would feel discomfort if the teacher was not the main authority of the learning. Their students might experience unease by the re-evaluation and revision of knowledge through consultation with others, and so may not achieve in their learning. Such sentiment was evident in relation to the achievement level of their students. Some of the students also expressed lack of tolerance for ambiguity and appeared not to trust their own ideas. One student stated explicitly that the teacher had the best ideas. Several other students commented that they felt embarrassed if they had the wrong answers.

Several teachers referred to the potential lack of suitable resources that would meet the learning needs of their students. This was also similar to Engeln, Euler et al. (2013) findings that teacher views of available, suitable resources could become a factor in determining the adoption of IBL. As the medium for learning was Arabic, and the number of appropriate websites in Arabic is more limited than in English, then this would not be an unreasonable concern.

15.9.1 Determining Mitigating Factors

Aikenhead (2005) had found that, while teachers may appear to support the notion of inquiry, they may actively undermine new practices. The science and mathematics teachers involved in the introduction of IBL in this study seemed to support the notion of inquiry, but also expressed significant concerns. The use of the two didactic tools in introducing IBL was intended to support teachers by giving them practical classroom strategies. They were intended to be manageable within curriculum requirements and have the potential to alleviate factors related to external realities. However, many of the concerns raised by the teachers may relate to views of quality teaching, and it is not so clear how much these views were influenced by external realities or arose from internally held beliefs.

Furthermore, Gillies and Boyle (2010) suggested that teachers' objections to the use of cooperative student-centred learning in their classes might only be partly due to the demands imposed by the curricular organisation. Rather, they might relate to teachers' lack of knowledge. All the teachers in this project were well qualified and confident in their specialised subject knowledge, however their knowledge of teaching practices in relation to IBL may not be so secure, and they may have felt less confident in moving to new practices that involve new classroom management skills.

Teachers' views of quality pedagogy along with their knowledge and confidence in extending their repertoire of teaching strategies become two possible mitigating factors. Another potential factor relates to the relationship between teachers' and students' views. In many of the classes, both in science and mathematics, students appeared to hold contrasting views related to the challenges and dialectic interplay of IBL in relation to academic risk-taking (Meyer, Turner, & Spencer, 1997). Some students tolerated uncertainty, error and confusion because their focus is on the larger goal of understanding, while those students who fear challenge might wish to avoid risks and ambiguity. They are more likely to focus on performance and what they are learning in one lesson. Those students who aspire to independent skills and responsibility for their learning are more likely to be those that aspire to larger and longer term goals.

Calleja (2016) indicated that, in developing new classroom practices, the communication between teachers and students is paramount. The teacher plays a guiding role in situating new classroom norms, releasing control to students and in encouraging student efficacy to engage in new challenges. How this is managed can have a considerable impact on the way IBL is developed and on student learning. Where teachers lack confidence in their own use of new practices, students may still feel challenged in sharing control in their learning with their teacher.

Taking these mitigating factors into account, the use of the didactic tools might be undermined. For example, WebQuests might become another process to support the continuation of structured approaches to inquiry, rather than helping the teachers to overcome the perceived risks.

15.10 Concluding Remarks

In introducing IBL in these Qatari science and mathematics classrooms, through the PD, it was becoming clear that a range of factors challenged some of the teachers. The potential for external influences is real but mitigating factors may relate to internally held views of teachers and students. Both teachers and students may need to unlearn established expectations in their classrooms, and this unlearning may involve challenges, risks and discomforts. While the initial analysis of the post IBL data tentatively suggested that teacher and student views were in transition, just how these transitions maintain over the ongoing engagement with IBL will be an interesting aspect of the research. In this regard, this case study of professional development in Qatar could help us to further understand the tension between theory and practice in shifting pedagogies through PD programmes.

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Chapter 16
Motivating Rural Students in STEM: Practices Contributing to Student Engagement with STEM in Rural Victorian Schools

Steve Murphy

Abstract A significant but largely overlooked equity issue in STEM education is the relatively low engagement and performance of rural students in STEM. Students from rural schools tend to achieve more poorly in the STEM disciplines and are less likely to engage in further STEM study than their metropolitan counterparts. This chapter reports on findings of an Australian project examining STEM education success in rural Victorian government schools. The project investigated the STEM practices of four schools that consistently attracted higher enrolments and achieved stronger results in senior STEM subjects, compared with similar rural schools. This chapter presents a cross-case synthesis of practices that appeared to contribute to the STEM success of these schools, and discusses the findings in relation to theoretical models of motivation and academic emotion. The four rural schools employed a complex array of practices to improve student engagement in STEM, including holding high expectations while providing generous support, place-based learning, STEM enrichment opportunities, and differentiated mathematics programs. While the practices employed are not restricted to rural schools, each school felt their rural nature facilitated these engaging practices.

16.1 Introduction

Students in rural schools perform more poorly than their urban counterparts in STEM. International and national testing suggests that Australian metropolitan students significantly outperform non-metropolitan students in mathematics, science and information and communication technology (Thomson, De Bortoli, & Underwood, 2017; Thomson, Wernert, O'Grady, & Rodrigues, 2017). Studies of Year 12 participation and achievement in Victoria show that metropolitan schools have higher average enrolments and achievement levels than rural and regional schools in senior mathematics and science (Murphy, 2018a, 2018b). Metropolitan students are more likely to be interested in science, enjoy learning science, and see science as contributing

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to their future careers (Thomson, De Bortoli et al., 2017). Students in rural schools are less likely to prefer science to other subjects, and are less likely to enjoy science subjects (Lyons & Quinn, 2010).

The disparity between rural and metropolitan student's achievement and engagement in STEM education is given some, but limited, attention in the various Australian jurisdictions' STEM strategies (Murphy, MacDonald, Danaia, & Wang, 2018). The National STEM School Education Strategy (Education Council, 2015) clusters rural students with other groups experiencing inequity in STEM, noting, "Girls, students from low socio-economic status backgrounds, Aboriginal and Torres Strait Islander students, and students from non-metropolitan areas can be less likely to engage with STEM education and therefore have a higher risk of not developing high capabilities in STEM-related skills" (p. 4). This strategy also recognises the dearth of evidence about effective STEM education in Australian contexts. It identifies five national actions, the fifth of which is to build a strong evidence base "to determine which approaches work best for different purposes and student cohorts" (p. 10). The research reported in this chapter responds to a need for research into effective STEM education practices in rural schools.

This chapter reports on a multiple-case study of the STEM education practices of four relatively high STEM performing rural Victorian schools. This chapter presents a cross-case synthesis of practices associated with improved STEM engagement, addressing the question:

What practices appear to contribute to student engagement in STEM education in high STEM performing rural schools?

16.2 Engagement in STEM

Despite a weight of evidence demonstrating that student dispositions towards STEM impacts on their achievement and the ultimate pursuit of STEM careers, student disposition is given limited attention in Australian STEM education strategies (Murphy et al., 2018). Where it is, vague terms are used, such as engagement, interest and aspiration, with little explanation as to what they mean or how they can be achieved. This chapter defines STEM engagement as a student's commitment to active involvement in STEM learning (Christenson, Reschly, & Wylie, 2012), with this engagement being behavioural, cognitive and emotional (Fredricks, Blumenfeld, & Paris, 2004). Further, this engagement is driven by learner motivation and academic emotions in STEM.

There are several motivational models that have been found to be predictive of achievement, participation and aspiration in STEM (Murphy, MacDonald, Wang, & Danaia, 2019). Expectancy-value theory (Eccles, 2009), particularly prominent in the literature, argues that student's expectations of success in learning, and the value they attribute to this learning (task value), impacts on student effort, engagement, and student learning choices. Students' expectation of success is strongly linked to their self-concept (their beliefs about their ability in a particular area) and their self-efficacy (their beliefs about their ability to complete a certain task) (Schunk, Pintrich, & Meece, 2008). Student self-concept in STEM has been found to be predictive of achievement (Liou, 2017; Petersen & Hyde, 2017). The task value for a student may be impacted by attainment value (the importance of doing well on a task), interest value (the enjoyment to be gained by doing a task), utility value (the long-term usefulness of a task) and cost (the effort and emotional impact associated with the task) (Eccles, 2005). Similar to student's self-concept, a student's task value has been shown to be predictive of STEM learning engagement, subject choice and career aspirations (Guo, Parker, Marsh, & Morin, 2015; Guo, Marsh, Parker, Morin, & Dicke, 2017)

Motivation is also theorised to be impacted upon by a student's sense of autonomy, sense of relatedness, mindset and goal orientation (Carmichael, Muir, & Callingham, 2017; Dweck & Leggett, 1998; Lazarides & Rubach, 2017; Wang & Holcombe, 2010). Autonomy supportive strategies, such as providing choice and welcoming student thoughts and feelings, have been found to be associated with higher motivation and engagement in mathematics (Carmichael et al., 2017), and higher motivation and achievement in science (Jungert & Koestner, 2015). Student perceptions of teacher care and support have also been linked with higher motivation and achievement in STEM (Wang & Holcombe, 2010). Students who believe that ability can be developed through effort rather than intelligence being unchangeable, have higher motivation and achievement in mathematics and science (Bostwick, Collie, Martin, & Durksen, 2017; Chen & Tutwiler, 2017). In mathematics, secondary students pursuing mastery goals by focusing on developing their understanding and academic competence show improved participation, effort and persistence (Lazarides & Rubach, 2017).

Finally, student's academic emotions have been found to impact on both student engagement and achievement in STEM. Negative emotions, such as anxiety, boredom and hopelessness are inversely correlated with effort and achievement in mathematics (Larkin & Jorgensen, 2016). Conversely, positive emotions such as enjoyment, improve student persistence and lead to stronger achievement in STEM (Simon, Aulls, Dedic, Hubbard, & Hall, 2015).

16.3 Engagement in Rural Schools

While significant research attention has been given to *participation* in education in rural schools (Cavanagh, 2014), far less has been given to rural student *motivation* (Hardré, 2011). The literature that does exist highlights various factors that appear to engage rural students in education. Teacher characteristics, teacher support and teacher–student relationships are all predictive of rural student self-concept and student interest in subjects (Gavidia-Payne, Denny, Davis, Francis, & Jackson, 2015; Hardré & Sullivan, 2008; Hardré, Sullivan, & Crowson, 2009). The perceived utility value of content impacts rural student effort, and personal learning goals and self-concept impacts on rural student interest and achievement in a subject (Hardré et al., 2009). It has also been argued that as rural students are closely tied to their immediate community, the local culture, resources and role models also impact student academic engagement (Hardré et al., 2009).

If the literature on student motivation in rural schools is scant, research investigating motivation in STEM in rural schools is rarer still. A study of a motivational model with rural Australian students found that persistence in mathematics was strongly correlated with students' self-efficacy and valuing mathematics (Plenty & Heubeck, 2011). This study found that motivation in mathematics was lowest in middle secondary school, linked with low perceived utility value, before recovering somewhat in senior years. Hardré (2011) contrasted engagement in mathematics against other subjects in rural schools and found that students felt that maths was less engaging, that they were less competent in mathematics, and that mathematics teachers were less supportive. This study also found a disconnect between mathematics and science teachers' perceptions of motivational factors and those of their students, with teacher instructional and interpersonal efforts to motivate students in these subjects not being received as intended.

16.4 Conceptual Framework

While it is acknowledged that a range of non-school factors impact on rural student engagement in STEM (Centre for Education Statistics and Evaluation, 2013), the research discussed in this chapter focused on the practices of educators and educational leaders believed to have contributed to engagement in STEM at four relatively high STEM performing rural schools. Each practice was seen to impact upon student motivation towards STEM and STEM education in different ways, and these could be aligned to the motivational constructs discussed in Sect. 16.2. Ultimately, by motivating students in these ways, these practices are assumed to contribute to student engagement with STEM learning, as depicted in Fig. 16.1.

16.5 Method

This study adopts a holistic multiple-case design with a replication logic (Yin, 2014). Four rural schools with higher than expected student engagement and achievement in STEM were selected for the study. They were first considered as individual cases, analysing qualitative and quantitative data collected about each school's STEM education success through interviews, document analysis, observation and interrogation of databases. Cross-case analysis was then conducted to identify practices associated with STEM engagement across these schools.

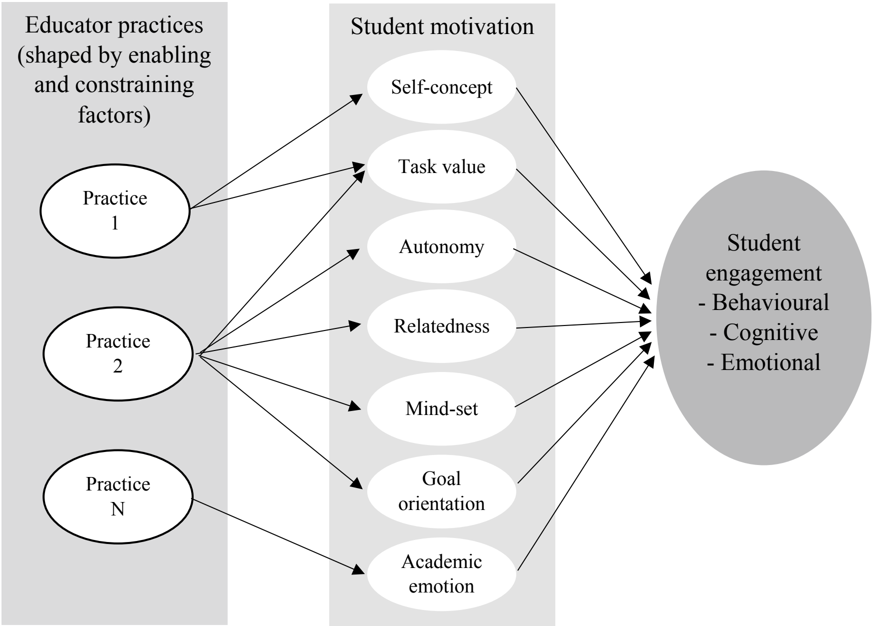

Fig. 16.1 The impact of various educator practices on domains of student motivation, leading to student engagement in learning

16.5.1 Case Selection

Schools vary in their average enrolment proportions and achievement levels in Victorian Certificate of Education (VCE) STEM subjects (Murphy, 2018a, 2018b). The four schools selected for this study are rural schools whose Year 12 2014–2016 cohorts had higher mean STEM enrolment proportions (out of all subject enrolments) in Year 11 and in Year 12, and higher mean STEM achievement level in Year 12, than other rural schools in the same socio-economic status quartile (herein referred to as “like schools”). Mean data across three years was used to mitigate for potential cohort effects. The four schools’ mean enrolment proportions and achievement levels, compared to the like school average, are shown in Table 16.1.

These four schools collectively represent the diversity of rural Victorian school contexts. All had secondary school enrolments of less than 300 students, and all were more than an hour’s commute to the nearest regional centre, and at least two hours from Melbourne, the state capital. RVC and SPC are P-12 schools, while ASC and CSC are straight secondary colleges. ASC has an Index of Community Socio-Economic Advantage (ICSEA) above the national average, CSC and RVC’s ICSEAs are only just below the national average, and SPC’s ICSEA is well below

Table 16.1 Mean enrolment proportions and achievement levels from 2014–2016 at case schools and like schools

	Mean Year 11 STEM enrolment proportion (%)	Mean Year 12 STEM enrolment proportion (%)	Mean Year 12 STEM achievement level (study score out of 50)
Sweeping plains college (SPC)	4.9	4.3	32.22
Like school average	4.2	4.2	26.54
River valley college (RVC)	4.8	4.6	29.79
Like school average	4.4	4.2	26.55
Coastal secondary college (CSC)	4.5	4.2	28.66
Like school average	4.3	4.1	27.83
Alpine secondary college (ASC)	4.7	4.2	28.23
Like school average	4.3	4.1	27.83

the national average (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2019). The schools serve communities with a diversity of dominant industries, including cereal production, beef, dairy, wool, forestry and tourism.

16.5.2 Participants

At each school, principals and all teachers of secondary STEM subjects were invited to participate in interviews about the school's STEM success. Current Year 12 students studying at least one STEM subject were invited to participate in group interviews. The numbers of participants at each school who gave consent and were able to participate in interviews are listed in Table 16.2.

Table 16.2 Type and number of participants interviewed at each school

School	Principals	STEM teachers	Year 12 students	
			Male	Female
Sweeping plains college	1	6	7	6
River valley college	1	8	3	3
Coastal secondary college	2	4	3	7
Alpine secondary college	1	7	5	6

16.5.3 Data Collection

Data were collected from multiple sources to allow for triangulation of findings (Yin, 2014) and to improve the overall credibility of the study (Tracy, 2010). Qualitative data were gathered during site visits through semi-structured interviews with participants (Gideon & Moskos, 2012). Staff were asked open-ended questions about perceived contributing factors and impediments to STEM education success at the school. Students were interviewed as a group and asked open-ended questions about their learning experiences and participation in STEM. The group interview was used as a way of encouraging adolescent participation, despite the inherent risk of conformity amongst participants (Cohen, Manion, & Morrison, 2011). The researcher addressed each question to each participant to mitigate against potential "group think". In most cases, STEM teachers and principals were interviewed individually, however on two occasions, in pairs, and on a further two occasions, in small groups due to time and availability constraints. Interviews took place in private and varied in length from 20 to 40 min. Interviews were recorded and transcribed, and the transcripts were used for analysis. School documents, including annual reports and student subject selection booklets were also collected for analysis. The researcher also toured the school accompanied by a principal or leading teacher, taking field notes and photographs of educational artefacts (for example, displays, resources and facilities).

16.5.4 Analysis

An explanation-building approach to analysis was employed for the case analyses (Yin, 2014), where a set of causal links were sought to explain how and why these rural schools had achieved greater than expected STEM success. Qualitative data was thematically analysed one school at a time. Data were coded using both deductive and inductive themes (Braun & Clarke, 2006). Data was first examined for activities associated with student dispositions in STEM. This was done by searching for synonyms and antonyms of the keywords identified by Murphy et al. (2018) in their analysis of Australian STEM education strategies, including engage, motivate, aspire, inspired, confidence, curiosity, resilience and mindset. Following this, through iterative engagement with the data coded as impacting on student dispositions at a particular school, inductive themes were identified, a process Braun and Clarke describe as "organic thematic analysis" (Braun & Clarke, 2006, p. 741). The prominent themes in participants' explanations of their schools' STEM engagement success are shown shown in Table 16.3.

Finally, cross-case synthesis was conducted (Yin, 2014), comparing and contrasting the practices associated with student engagement across the four different schools, and exploring the factors that enabled and constrained these practices at the different sites. This synthesis is presented in Sect. 16.6.

Table 16.3 Practice themes believed to contribute to student engagement in STEM at the four rural schools

STEM Practice theme	School			
	SPC	RVC	CSC	ASC
High expectations with support	✓	✓	✓	✓
Hands-on learning experiences		✓	✓	✓
Real world learning contexts	✓	✓	✓	✓
Place-based learning		✓	✓	
Science electives				✓
Differentiation in mathematics	✓	✓	✓	
Managing mathematics emotions		✓	✓	
STEM enrichment programs	✓	✓	✓	✓
Careers education	✓	✓		✓
Technical training	✓			

16.6 Practices Associated with STEM Engagement—A Cross-Case Synthesis

This section synthesises the practices associated with increased student engagement in STEM listed in Table 16.3 across the four schools, and considers their alignment to the theoretical understanding of motivation and emotion in STEM and rural education outlined in Sects. 16.2 and 16.3.

16.6.1 High Expectations, Generous Support and Passion

High expectations for students to do their best, backed by generous teacher support from teachers passionate about teaching and their disciplines, was a practice felt to improve student engagement at all four schools, as illustrated by this quote from an RVC student:

> The actual level of enthusiasm and commitment and how much these teachers care here, not even in the higher years, in the lower years as well, how much they actually care about the students and how well they do is awesome… it is one of the reasons why everyone is always doing harder subjects and always pushing themselves because they have teachers there that care and are putting in a lot of time and effort for it.

All four schools had established a culture of high expectation for learning in STEM, either within the school and in some cases beyond. Students said that teachers "push us," "expect you to do your best," expect students to "have a go yourself," and that they "just really want us to succeed." The expectation of effort and achievement seemed to be a social norm at the schools. Many students made comments like "it's okay to try hard," "everyone wants to do well," "it's seen as desirable to do well at school here" and "we want the rest of the class to do well as well," suggesting that achievement in STEM has attainment value for students at these school. At SPC parental support was also seen as a motivating factor by several STEM teachers, one who said, "parents always encourage them and support them and push them." However, at RVC and CSC, teachers noted that education was not always highly valued, and that home life, such as work on the farm, sometimes distracted from school engagement.

These high expectations were not seen as focused upon achieving high grades in STEM, but rather on effort and continual improvement, reflecting a mastery goal orientation. An ASC teacher said, "[It] doesn't matter where you start, it matters that you grew from where you were to where you are now." The students felt that expectations were reasonable and achievable, particularly with the level of support teachers offered. An ASC student commented:

> They don't expect so much that they make it an impossible thing to achieve those goals. But they try and help you along… but not to the point where they're doing it for you. Just enough to get you to where you need to be.

Students saw the ready and plentiful support offered by their STEM teachers throughout secondary school as motivating. A CSC student commented "The thing that I've really loved since Year 7… I'm not the smartest at the top, but I always feel like I've got that help in hand. I'm not always behind." STEM teachers offered help at lunchtime, after school and during holidays. RVC and CSC both ran formal after school homework programs attended by students of all ages, with a focus on mathematics. Many teachers shared contact details with their senior students, and several teachers at RVC made use of Facebook groups to support senior students after school hours. Students also felt that this level of assistance was not common in other schools. An RVC student said, "I think everyone's aware that not many schools get that sort of treatment… everyone's free to go… and, yeah I'm sure that makes a hell of a difference to our results. And that's done from a young age too."

Teacher support seemed to impact student self-efficacy, but also seemed to be motivating as it enhanced student-teacher relatedness. A CSC student commented, "You do wanna impress them because you do have that relationship with them and you wanna show that their teaching's not going to waste."

The schools recognised that the scale of the school and the nature of rural communities facilitated offering this level of support in STEM. Small class sizes made offering individualised support more feasible, however this only goes part way to explaining the degree and success of the support offered. The quality of teacher-student relationships, and in some cases teacher–family relationships were frequently presented as the motivating force behind the support offered and the reason for its uptake and success. STEM teachers across the schools spoke about how their involvement in local sporting bodies and community groups contributed to their relationships with their students. Others felt their role as a parent at the school had been important. One SPC teacher explained her willingness to work hard for her students, saying, "These are kids of people I know, I've had my kids come through, and you just want the best for them." An SPC student reflected, "I think in rural areas…we're seeing our teachers all the time and not just in school but outside school… so you've got a bit more of a personal relationship with them than just that work sort of relationship."

A further factor cited as contributing to student engagement in STEM at the schools, and present in participant discussion of expectations and support, was the obvious passion of the STEM teachers for their discipline and their teaching. The SPC principal said, "I think that [students] know there's some strong passionate teachers in those areas and they choose accordingly." Many teachers across the schools believed teacher enthusiasm increased student interest in STEM, commenting, "teachers are enthusiastic, and that wears off on kids" and "teachers are passionate which inspires students in the area". Students said that their STEM teachers were obviously interested and excited about what they were teaching and that "has a trickle-down effect on kids." Student comments such as "makes you excited to learn" and "you're just entertained by that" suggests that the teacher's passion fostered positive emotions towards STEM. Students felt that teacher enthusiasm also motivated reluctant STEM learners. An RVC student said, "She was just really enthusiastic, just loved her maths and, well, even if not everyone did, they learnt a hell of a lot… She just kept everyone going." A student from CSC who self-identified as a reluctant STEM learner said of her STEM teachers, "They're actually having a good time and smiling and asking questions and being all enthusiastic about it, then like 'oh that's cool'."

16.6.2 Hands-on, Real-World and Place-Based STEM Learning

Hands-on activities, real-world learning, and place-based learning were believed by participants to contribute to student STEM engagement. Hands-on learning involves students learning by doing, through using equipment and concrete materials (Flick, 1993). Real-world learning involves learning applied to contexts relevant to students' current lives, futures or wider world issues. Place-based learning is a subset of real-world learning, involving learning in and/or applied to local areas and contexts, and often includes hands-on activities (Centre for Education Statistics and Evaluation, 2013).

Hands-on activities were understood to contribute to the interest-value of tasks, as well as fostering positive academic emotions. Teachers described an extensive range of hands-on activities across the study, including building spaghetti bridges, constructing and racing cars, launching rockets and Barbie™ bungee jumping, variously asserting that these activities "get[s] them interested," "sucks them in" and were "cool" and "fun." The CSC mathematics leader felt that without the use of "equipment and hands on stuff…you're going to lose them straight away." Students across the schools nominated hands-on activities as increasing interest in STEM, with one CSC student suggesting the lack of hands-on opportunities in other subjects rendered them "really bland and kind of boring." A CSC student suggested that hands-on activities are particularly important for rural students, "Well most of us are from farms and stuff and we are hands on when we're out there helping your dad or something… so when we come to school we want it to be hands on again."

Real-world learning occurred across all schools and was seen to increase the perceived utility value of STEM. In mathematics, many teachers spoke about using real-world contexts, including finance and sport, for problem-solving. Mathematics teachers as SPC worked systematically to connect learning to real-world contexts, writing on the board at the beginning of the lesson the real-world reason for the focus of the lesson. Science and technology classes often simulated real-world contexts; for example, a mock-up body farm in forensic science at RVC, and designing and building model Formula One cars at SPC. Students commented that real-world learning is motivating as it shows that "there's a real-life connection to it" and that they "could probably use this in life."

ASC's science elective program, which extends from years 8–10, seemed to impact student engagement in STEM, through improving task value, autonomy, and academic emotions. This program included units with obvious real-world connection such as "Small engines", "Medical science", "Robotics", "Animal science" and "Forensics and psychology". Students commented that the electives were "really fun" and effective at "drawing you in". Enrolment numbers also suggest that the science electives were particularly engaging, with science electives attracting more student preferences than other subjects. Staff felt that the students valued the opportunity to choose their science subjects and that the hands-on and real-world nature of the subjects resulted in higher enrolments in VCE sciences. It is worth noting that science was also offered as an elective in Years 9 and 10 to the 2014–2016 cohort at both CSC and RVC, though participants at these schools did not highlight this element as contributing to STEM engagement.

Place-based STEM learning was viewed as a key practice at RVC and CSC, but was also present to some degree at the other two sites. It was seen as contributing to engagement through improved task value, as well as by enhancing relatedness, autonomy and positive emotions. Place-based learning experiences included students constructing bin-targets to minimise school littering at RVC, raising cattle as part of the Cows Create Careers program at RVC and SPC, construction of wombat-proof storage boxes for campsites near CSC and public lighting sculpture installations near ASC. Common to many of these experiences was the opportunity for students to connect with other students, adults and the wider community. For example, RVC secondary students frequently shared their STEM projects with students in the primary school, and ASC students worked with local experts in water management and power generation. Place-based projects typically supported student autonomy, with students contributing significantly to the planning and implementation of projects. For example, some CSC students campaigned successfully for a plastic bag free retail sector, while others were involved in habitat regeneration at a local creek.

Several staff at RVC and CSC felt that place-based learning particularly suited their rural students and that there were rich resources in rural areas for this learning approach in STEM. A CSC principal commented "I think it's something that the kids are interested in, the outdoors. And they get more access to that here in the country." Students also valued the use of rural contexts for STEM learning. One CSC student, describing local ecosystem investigations, said, "I think that was pretty cool, just knowing that you can do that kind of test in local environments."

16.6.3 Differentiation and Managing Academic Emotions in Mathematics

There was an emphasis at three of the four schools on mathematics education practices that tailored learning to individual students and built student confidence in mathematics.

RVC, CSC and SPC all used differentiated instruction in their mathematics classes, albeit in different ways. Differentiated instruction involves a cycle of pretesting, goal setting, individualised instruction and practice, and post-testing (Prast, Van de Weijer-Bergsma, Kroesbergen, & Van Luit, 2015). At CSC, the delivery of this program was largely paper-based, with instructional programs kept in colour-coded folders, and students using worksheets and text-books. After a topic pretest, students are allocated a colour-coded task sheet from which they select and complete various tasks, which they self-assess. Each task is assigned a star value and students need to earn a certain number of stars before they are ready for the post-test. At RVC and SPC the programs are managed through an online learning management system, with students using spreadsheets to track their learning, and accessing some instruction and practice materials online. SPC publicly displayed student progress on a large chart in the classroom, and gave regular mathematics awards at assemblies for effort and improvement. It was noted that some students at both RVC and SPC were also accessing the online component of these programs from home.

This approach to mathematics delivery was seen as improving student self-efficacy and autonomy, while minimising student boredom and disengagement. A CSC student commented that through the program, "my confidence boosted up and then my marks went up because… I wasn't thinking in my head, I'm terrible at this, I don't want to do it." The numeracy leader at SPC said that, through the program, students are "building that independence and actually working towards achieving their goals and learning more and more." An ASC teacher felt that student autonomy was a key aspect of the approach, commenting, "It's the kids' data. They need to own it… Same with learning goals." Students across the schools said differentiated instruction meant they did not "stagnate" or "keep going over the same sort of stuff" and that they are "not getting bored." The mathematics leader at CSC felt that differentiated instruction kept all students engaged, commenting, "There's never gonna be a time that you need to go off with the fairies or muck around because it's always gonna be something that you can do."

In addition to the differentiated structure of mathematics education, there was also a strong awareness of the importance of managing students' academic emotions in mathematics. The numeracy leader at RVC commented that maths is "the worst subject as far as damaging kids. It's really bad" and a teacher from ASC said, "If a kid thinks that they're dumb at maths, forget about it, that's it." Efforts were made at each school to ensure that teacher–student interactions contributed positively to student engagement in mathematics. An RVC teacher said "It's not, 'oh you got the right answer' but 'look how much you've improved by', [or] 'I know that you have difficulty in this' but 'look how I can help you'." A CSC student reflected on her experience, "I got to Year 7 and my teacher was fabulous. I'm like, look I'm not confident in Maths, I don't think I'm very good and she's like, no you can do it, you're fine… we're gonna change your mindset and get you into it."

16.6.4 Raising the Profile of STEM Through Enrichment Programs, Careers Education and Technical Training

In one form or another, STEM seemed to have a high profile at each school. An ASC student commented, "I don't know what it is specifically, but there seems to be a large STEM culture in this school." A RSC student felt "We're quite a strong science based school … we're in an ag. community and science is probably something that most of us probably look at". SPC is known for its mathematics and technology, with one teacher saying, "I just think the students, for whatever reason, seem to be able to pick up maths or enjoy maths or … feel that maths is something that once they get into it they can use it for lots of other things." At CSC the STEM teachers have a strong reputation within the community, "We're sort of well-known around the community and we're strong, respected."

While the classroom programs contribute to the profile of STEM, each school employs additional activities that are seen as raising the profile of STEM and improving student engagement. ASC STEM teachers organise extensive extracurricular STEM activities drawing on grants and support programs to allow their isolated students to participate in these enrichment opportunities. Students found these programs engaging, a typical comment being, "They definitely try and push more experiences and opportunities on us, which I think that's why everyone is quite passionate about it." At RVC, senior classes regularly share their STEM learning with junior students, and students organise and run well-attended STEM events for students and their families. RVC also runs other high profile activities that are STEM related, such as emergency service days, and firefighting training. CSC STEM teachers felt that their strong promotion of STEM to parents and students at information nights leads to increased senior enrolments. CSC also felt its outdoor education and community service programs also contributed to the profile of STEM at the school. SPC teachers strongly promoted mathematics education, through regular contributions to the school newsletter, awards at fortnightly assemblies, and occasional whole-school mathematics days. SPC teachers also felt that their extensive STEM-related technical training programs in careers like building and construction, agriculture, animal science, and allied health, contributed to the STEM profile at the school.

The schools leveraged strong relationships with the local community to run many of these programs. Community groups like Rotary and Lions support the STEM enrichment experiences at ASC. RVC and CSC collaborate with local services and volunteers to run many of their programs. The VET programs at SPC are dependent on the school's collaboration with local employers and nearby schools.

Though not strictly a STEM education practice, three schools felt their extensive careers education programs contributed to the profile of STEM and their high enrolments in senior STEM subjects. SPC, RVC and ASC all have careers classes, commencing in years 7, 8 and 9, respectively, and continuing into the senior years. There are also annual career information evenings and individual counselling for senior students. The SPC principal commented, "That really, I think, supports students when they're making choices for subjects entering into VCE, there's great knowledge there and recommendation regarding the need for your maths subjects for example." Many teachers referenced careers education at their schools as a factor in explaining high VCE STEM participation, saying the programs offer students a "really clear structure" and make students "comfortable with their future career choices." Students also felt that the careers program encouraged the choice of senior STEM. One ASC student said, "I think they kind of know where you want to head, like what direction you want to go in career wise, so they can help you aim for those subjects." Another student noted that the programs encouraged students to consider growing STEM-related industries like "more aged care and more health and medicine areas."

16.7 Discussion and Conclusion

Each of the four rural schools engaged in a complex array of practices believed by the participants to contribute to the above-expected STEM success of their schools, particularly by maximising student engagement. The participants' responses suggest that these practices motivated students to engage with STEM learning in various ways, as summarised in Table 16.4. As can be seen in this table, practices believed to contribute to the schools' STEM success were most often described as impacting on task value, aligning with the work of Guo et al. (2015). These practices were commonly described as highlighting the utility value of STEM, involving interesting activities, and contributing to STEM achievement being viewed as desirable. Another motivational construct commonly viewed as influenced by the school's practices was academic emotions, in line with the findings of Simon et al. (2015).

Some practices were felt to impact on motivation through a range of mechanisms. Maintaining high expectations with generous support was viewed by each school as a key contributor to STEM success. This practice was described as impacting student motivation through fostering self-efficacy, attainment value, relatedness, mastery-goal orientation and positive feelings towards STEM. This finding builds upon those of Wang and Holcombe (2010) and Hardré et al. (2009). However, where these authors emphasised teacher support and teacher–student relationships, the schools

Table 16.4 Practice themes believed to contribute to student engagement in STEM by motivational construct

STEM practice theme	Motivational constructs						
	Self-concept/self-efficacy	Task value	Autonomy	Relatedness	Mindset	Goal orientation	Academic emotion
High expectations with support	✓	✓		✓		✓	✓
Hands-on learning experiences		✓					✓
Real-world learning contexts		✓					
Place-based learning		✓	✓	✓			✓
Science electives		✓	✓				✓
Differentiation in mathematics	✓		✓				✓
Managing mathematics emotions	✓				✓	✓	✓
STEM enrichment programs		✓					✓
Careers education		✓					
Technical training		✓					

in this study coupled these to holding high expectations for STEM learning. Further, the passion STEM teachers had for their subjects was seen as facilitating this practice.

Each school variously acknowledged the contribution of hands-on learning, using real-world learning contexts, or place-based learning to their performance in STEM education. Of these, place-based learning seemed to impact the broadest range of motivational constructs, providing interest and utility value, supporting autonomy, using student connections to their locality and fostering positive emotions. This finding adds support to recommendations for place-based learning to foster rural student engagement (Centre for Education Statistics and Evaluation, 2013).

There was a particular focus on promoting positive mathematics self-concept in three of the schools. Well-resourced and highly differentiated mathematics programs were felt to build student self-efficacy, and provide student autonomy. The structure of the mathematics program was carefully supported by teachers who attended to the emotional welfare of their students, encouraging effort and building student confidence with appropriate support. These rural schools did not follow the trends noted by Hardré (2011) in rural schools of low student self-concept in maths and less supportive mathematics teachers. Interestingly, however, the case schools did not place the same emphasis on self-concept in science and technology subjects.

There were also a range of autonomy supporting mechanisms used by the schools, including science electives, self-directed mathematics learning, and several of the place-based learning programs. While it has been theorised that autonomy-supportive practices are motivating (Carmichael et al., 2017), participants in the case schools only rarely spoke about student autonomy as contributing to student engagement in STEM.

Some other aspects of engagement theory were relatively absent in participants' accounts. When discussing expectations, support and managing academic emotions, there was a focus on improvement across the sites, however only STEM teachers at RVC had adopted an explicit growth mindset approach. There was some evidence of students being involved in goal setting, particularly associated with the differentiated mathematics program, though these goals seemed associated with meeting benchmarks and targets rather than being true mastery goals.

Some of the practices associated with STEM engagement were facilitated by the rural location of the schools. The small school size and closeness of the rural community was seen as contributing to STEM teacher-student relatedness, and to teachers' abilities to understand and address the academic and emotional needs of each of their students. The schools made extensive use of the local resources and community networks to facilitate real-world and place-based learning, as well as to support their careers and technical training programs. This adds weight to scholarly arguments that effective rural schools capitalise on the characteristics of their local community (e.g. Hardré et al., 2009). For other practices associated with STEM engagement, the rural location was an impediment, with schools noting difficulties in funding and accessing STEM enrichment opportunities.

This multi-case study identifies numerous practices associated with STEM engagement at four relatively high STEM performing rural schools, including holding high expectations with generous support, place-based learning, STEM enrichment opportunities, and differentiated mathematics programs. While these practices are not peculiar to rural schools, the schools' rural nature, including their small communities, close relationships, and local resources, were seen as facilitating many of these practices. However, this study cannot conclude that any one practice, or set of practices, led to high STEM engagement at these schools. Given this, it does not describe a generalisable approach for implementation by other schools, but rather provides transferable insights into STEM education practices that may build student engagement and achievement in STEM, particularly in small rural schools. Further research into student engagement practices in other high STEM-performing rural schools, along with a comparison with practices at less STEM successful rural schools, would build on the findings of this study, offering more direction to rural schools and policymakers hoping to improve the engagement of rural students with STEM.

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