School Innovation and K–6 STEM Learning: A Narrative Inquiry

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Rosemary Irvine, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy in the Faculty of Arts and Social Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

Innovation has become a policy priority internationally, with policymakers worldwide looking to education systems to nurture a generation of innovative and creative future workers to meet social, environmental, and economic challenges. Among the abilities listed as essential in the innovation era, skills in science, technology, engineering, and mathematics (STEM) are acknowledged as paramount for future success and prosperity. Alongside this is an appreciation that the focus in school must change from traditional educational priorities and teaching methods to those which develop students' skills that prepare them for a society and economy that values innovation. Within this landscape, debate has emerged about the integration or teaching of STEM subjects in schools and the capacity of education systems, many of which feature standardisation as a consequence of neoliberal education reform, to accommodate innovative approaches to STEM education at the school level.

This study uses a research design underpinned by a pragmatic sociocultural perspective to investigate how schools can innovate for STEM literacy. The overarching research approach is that of narrative inquiry, which recognises the innate inclination in human beings to use storytelling to solve problems and to relate to the world and its phenomena. An international Delphi study was carried out in the initial phase of the research to extrapolate a comprehensive definition of school innovation, elicited via the perceptions of experts in the field. Phase two involved investigating examples of K–6 STEM learning innovation in schools in Ireland, Australia and the US, uncovering stories through the lived experiences of teachers and school leaders in schools influenced by different educational traditions and policies. The study presents findings that generate fresh and nuanced understandings of school innovation and school innovators, as well as the factors influencing the teaching and leadership of K–6 STEM learning innovation. The primary (K–6) context of the study is particularly significant, given the recent calls for early exposure and intervention in STEM learning.

This research establishes a contemporary definition of school innovation, which enables a criteria for evaluating the experiences of STEM learning innovation as well as innovation in schools more broadly. Uncovering the key elements of leadership and school culture associated with innovation in schools, the study also identifies a model of for fostering innovative school leadership characterised by *trust*, *experimentation*, *aim*, *mindset,* and *solutions*. The study produces important findings for the way that innovation is viewed as an aspect of teaching and leadership by school systems. The findings imply that school systems should emphasise teacher engagement and professional learning not only for STEM teaching expertise but for the types of capabilities and behaviours suited to innovative teachers and school leaders. Further findings highlight the possibilities and difficulties of school innovation and K–6 STEM learning innovation in the current context of global policy influence and education reform.

Chapter 1

Introduction

> Innovation as a strategy can be used as the driving force for all types of development. If this is the case, why is innovation not employed more often as a strategy to improve schools and advance education? Why is innovative thinking not a characteristic that is nurtured more often in classrooms from preschool to high school? Simply put, becoming an innovator requires letting go of the old and exploring the new; this often requires a set of activities that are not commonly employed by schools. (Whitehead, 2008, p. 106)

This introductory chapter outlines the background and purpose of studying innovation in schools and Science, Technology, Engineering, and Mathematics (STEM) learning innovation (see 1.8.3) in primary (K–6) settings. It introduces the story of the contemporary, interconnected economic and sociocultural phenomena innovation and STEM, and explains how these global policy priorities have become calls to action for schools to produce future STEM innovators. The chapter also paints a picture of the current status of innovation and schools, and STEM learning in schools, and outlines the significance of the study in influencing innovative approaches to STEM education in K–6 settings and in schools more broadly.

As will be shown in Chapter 3, this study was borne from what Dewey (1978) termed a "felt difficulty" and the researcher's desire to interrogate and resolve a conflict between the rhetoric of innovation and STEM in schools and the "lived experiences" of teachers and school leaders. The overarching framework of the study is narrative inquiry, a qualitative research method that recognises the innate inclination in human beings to use storytelling as a way of solving problems and relating to the world and its phenomena (Haven, 2007; Webster & Mertova, 2007). Therefore, this chapter begins with what is referred to in narrative inquiry research as a *narrative beginning* (Clandinin et al., 2007) that speaks to the researcher's relationship to and interest in the study. This essentially forms a preface in the story and to the chapter that outlines the researcher's experiences, thoughts, and beliefs in relation to schooling, innovation, and STEM education before presenting the research problem.

1.1 Narrative Beginnings: My Story

> The personal justification comes from the importance, in narrative inquiries, of situating yourself in the study. We do that by writing something we call narrative beginnings that speak to the researcher's relationship to, and interest in, the inquiry. (Clandinin et al., 2007, pp. 24-25)

As will be described in Chapter 3, the methodology chapter, narrative inquiry assumes personal involvement by the researcher and is not about "dispassionate chronicling of experiences and events" (Kramp, 2003 p.114). It is necessary, then, as part of this research to conduct a *narrative beginning*, which speaks to my relationship as a researcher to the study.

I was born the child of two teachers. For my parents, who met at teacher's college, teaching was not just a job; it encompassed their whole lives, and consequently the lives of their children. Their passion was education and most of our family friends were educators. They entered teaching at a time when it was a highly sought-after profession in Australia and in NSW, where you had to achieve top academic results and were awarded a scholarship to teach. In other words, the very best students were paid to become teachers, and teaching was a prestigious and valued role in society. For a large part of my childhood, we lived in regional NSW and the schools were the centres of life within the town. Two of the country schools I attended were aptly named "Central Schools", with students from Kindergarten through to Year 12. My father went on to become principal of several schools, including one I attended myself and later one that I taught in. My mother was also a teaching principal of several schools as well as an assistant principal.

Dad was an early adopter in the use of technology in schools, teaching computers and programming in the 1980s and setting up a way for rural and remote schools to connect with each other to collectively offer a broader range of subjects to students via "telematics". He was also creative in other ways in the classroom and when organising school events and student learning experiences. I would witness him get up in the early hours in the morning, unable to sleep, jotting down his ideas about ways that he could creatively structure staffing and finance to deliver more opportunities to students. He was driven by a love for public education and an understanding that a great school could make a difference in the lives of students. I could see, even as a child, and more clearly as an adult and teacher myself, that his aim was to provide the students in his schools the same if not better opportunities than students at the most expensive private schools. This sentiment has strongly influenced my own school leadership narrative. Dad was entrepreneurial in his leadership until his retirement, with his final school known for its highly innovative teaching and learning programs.

I expressed interest in becoming a teacher at an early age. When it came time to make a career decision when applying for university, it may seem strange that my parents, who had passionately devoted their lives to teaching, discouraged me from studying education. It was the mid-1990s and things had changed since they entered the profession in the 1970s. University entrance ranks for teaching were low, representing the lower value placed on teaching as a career choice for young Australians (Leigh, 2012), and the academic aptitude of teachers had declined over the decades (Leigh & Ryan, 2008). It was not the highly prized role it once was, and no longer were the best and brightest entering teaching. My father had also reflected over the years about the sociopolitical influences in school education – the conditions, laws, regulations, policies, practices, traditions, and ideologies influence and define education at any given time (Nieto, 2006). Depending on the changing political contexts, he expressed that these could have a large impact on job and therefore life satisfaction. Since my own academic aptitudes lay in writing and communicating, I chose to study communications; however, at different points in my study and my subsequent career in communications and finance I considered revisiting this choice and studying teacher education. I made that switch during the career break I had taken to have children.

When I began teaching in K–6 schools in 2009, I brought with me experiences I had gained working as a public relations consultant in different settings and as a political staffer in federal parliament. These influenced the way I approached teaching. I remember being surprised at some of the teaching practices that were outdated and would not reflect productivity efficiencies in the business and wider public sectors. For example, there was limited use of email among some staff members, and instead there was heavy reliance on things like notes in pigeonholes as a way of communicating with each other. While using technology was non-negotiable in business and government, it appeared to vary greatly among schools. One school would be an early adopter of technology-enhanced learning and feature an openness among staff to try new things, while another would feature an underlying anti-change sentiment and a reluctance to adopt new technologies in the classroom. At school I had been interested in technology and had a achieved a result in the top 10 percent of the state in computer studies in my Higher School Certificate, the final high school qualification in NSW. I had also had a computer programming job while at university. I was interested in using technology in my own classroom; however, I was even more interested in the apparent lag between practices with technology and the pace of organisational change within and outside of schools.

In 2016, I was awarded a Premier's Teacher's Scholarship for leadership. My chosen topic of interest was innovation and creativity in schools and in 2017, as part of the scholarship, I embarked on a 5-week international tour to study schools and education organisations and to attend conferences. A large focus of the tour was the teaching of STEM in schools, and given my own context, I was most interested in teaching K–6. When witnessing innovative practices with STEM in different school settings in the UK, the EU, and the US, I was interested in the conditions that allowed some of these practices to emerge and thrive, and I wondered if I would have the same success in my own school system in Australia. The tour made me curious about the micro, meso and macro aspects in schools that would enable or inhibit the innovative teaching of STEM in K–6. In addition to implementing some of the STEM practices I had observed and widening my knowledge of K–6 STEM teaching via networks and professional learning, I applied to undertake PhD research on this "felt difficulty".

1.2 The Innovation and STEM Education Narrative

> The key task for educators is to prepare learners to be capable of participating creatively in an innovation economy. (Sawyer, 2006, p. 42)
>
> STEM education needs to be at the forefront of disruptive and innovative thinking. (English, 2018, p. 2)

Innovation has become a policy priority internationally. Increasingly over the last three decades, policymakers have become concerned about the role of innovation for economic performance, as well as societal and environmental challenges (Elder, 2017).

This can be seen in the policy output of the Organisation for Economic Co-operation and Development (OECD) (OECD, 2015a,b,c, 2016a,b,c, 2018, 2019, 2021), the United Nations (UN) (United Nations, 2015), and in governments schemes and policies across the Western world (OECD, 2016b, 2020). The OECD recognises the economic importance of innovation and the urgent necessity for nations to seize the potential of innovation to enable growth and jobs, improve well-being and better health outcomes, and to solve global problems like climate change (OECD, 2015a). There is also an understanding that unprecedented innovation in science and technology, for example in artificial intelligence and biotechnology, is driving economic, social, and institutional models (OECD, 2018). Similarly, the UN prioritises fostering innovation as part its Sustainable Development Goals (United Nations; 2015). Indeed, with the recent global challenges associated with the COVID-19 pandemic, the OECD (2021) has celebrated the success of innovation in responding to challenges (for example, in the rapid development of COVID vaccines) while highlighting the dangers of the disruption to innovation systems that can lead to reduced productivity and economic resilience. It has also called for a renewed acceleration of government innovation initiatives globally.

Within this call to innovation, policymakers have been looking to education for long-term assurance that future economies will be innovative. The first of the OECD's Innovation Strategy's (OECD, 2015a) five "concrete areas for action" is the importance of knowledge and skills for generating and implementing new ideas and technologies. As part of this area for action, it mandates a broad and inclusive education and skills strategy to cater for a future based on innovation.

Australia's policy response to the OECD innovation focus, the *National Innovation and Science Agenda* report (Commonwealth of Australia, 2015), similarly acknowledges that innovation and science are critical for growth, wages, and continued economic prosperity. This innovation agenda recognises the need for a cultural shift to encourage more Australians to embrace risk and entrepreneurialism, and it refers to education as a leading driver in enabling an "innovative culture". Indeed, education has been named as the first of five imperatives for action in Australia's "global innovation race", as outlined by Innovation and Science Australia (2017). This plan of action includes responding to the changing nature of work by equipping all Australians with skills relevant to a "2030 society". These skills are defined as digital skills, interpersonal skills, creativity, problem-solving ability, entrepreneurial skills, and skills in science, technology, engineering, and mathematics (STEM). The National Innovation and Science Agenda (NISA) announced by the Australian Government in December 2015 included among its initiatives a shoring up of "future skills base" through a $99 million investment in programs to boost digital literacy and skills in STEM amongst young Australians (Department of Industry, Innovation and Science, 2015).

The Australian policy statements mentioned are just three of the many linking innovation and education in recent decades, beginning with the Howard government's Backing Australia's Ability initiative in 2001 (Ferguson, 2005), which was aimed at demonstrating the solidified "symbiotic interrelationships between Australia's education, economic, innovation and technologies polices" (Moyle, 2010, p. 6). In summary, the Australian government has posited that the key to a prosperous future for Australia lies in the education system delivering innovative and creative citizens. In recent years it has emphasised STEM skills as key among the range of skills providing this innovation.

Policy initiatives to drive innovation through the strengthening of STEM skills in the US predate the current focus in Australia. The need to strengthen science and mathematics education in the US has been emphasised in multiple education reports since the early 1980s (Breiner et al., 2012). In its more recent policy programs, innovation has been explicitly linked with STEM skills. For example, the US Government's "Educate to Innovate" campaign (Whitehouse, 2009) listed as its goal the improvement in the performance and skills of American youth in STEM content at all levels of education through collaborative efforts of the federal government, leading companies, non-profit groups, and educational societies. As part of this initiative, it established public-private partnerships worth over USD 700 million in achieving STEM education priorities including preparing "new and effective" STEM teachers. More recent US policy documents are claiming that STEM education has evolved from "four overlapping disciplines toward a more cohesive knowledge base and skill set critical for the economy of the 21st century" (National Science and Technology Council Committee on STEM Education, December 2018, p. 1).

In the UK, the initial focus was on science, engineering, and technology (SET), but by 2006 it had also become STEM (Blackley & Howell, 2015). In 2007, the UK government announced "a major campaign to enhance the teaching of science and technology", acknowledging that "potential problems lie ahead" and the need to "to address the STEM issues in schools" by raising the "numbers of qualified STEM teachers by introducing, for example, new sources of recruitment, financial incentives for conversion courses, and mentoring for newly qualified teachers" (Sainsbury, 2007, p. 6). According to Hoyle (2016), education policies in all four countries of the UK reflect the centralised strategic aim to improve "the supply of home-grown talent in science and engineering" (p. 2), which is an issue common "across Europe and the UK that vexes governments, employers and educationalists" (p. 1). Indeed, throughout Europe, countries have renewed their policy portfolios to boost innovation culture and skills by increasing public budgets to expand STEM education (OECD, 2016b). This policy emphasis on STEM education in driving innovation has also seen some European countries undertake policy initiatives to make learning STEM subjects more attractive to young people and to implement new training programs and recruitment criteria for teachers.

A persistent theme in these policy statements regarding innovation in schools is the link between innovation and STEM skills (OECD, 2016b,c). Alongside this is a widespread acknowledgement that the focus in education systems must change from traditional educational priorities and teaching methods to those that will help students develop the skills that "prepare" them for a society and economy that values innovation (Law, 2008; Moyle, 2010; OECD, 2018; Zhu et al., 2013).

1.3 Innovation and Schools

The need for schools to embrace innovation to reflect the needs of a continually changing world is strongly represented in the literature (Aslan & Reigeluth, 2013; Beare, 2001; Christensen et al., 2008; Fullan & Langworthy, 2014; 2014; Hargreaves, 2003: Istance, 2011; OECD, 2001, 2010, 2016a; Peters, 2003; Sawyer, 2006). An overarching theme is that schools were designed in the 19th and early 20th Centuries to meet the economic needs of the industrial economy and should be modernised in line with contemporary economic and social priorities. Further, it is argued that schools are not adequately responding to the learning opportunities provided by radical advances in technology (Chatterji, 2017; Thomas et al., 2015), nor do the traditional and institutional aspects of schools reflect the needs of the knowledge and innovation economy (Fullan & Langworthy, 2014; Hargreaves, 1999; Moyle, 2010; Reigeluth & Karnopp, 2013; Voelpel et al., 2006).

Dramatic advances in technology continue to alter human experience. Our means of connecting, engaging, collaborating, transacting, and working have been transformed (OECD, 2010a, 2016a). Yet while access to information and interaction via digital communication has become a non-negotiable for students at home and in their social lives, experiences with digital technologies may be marginal in their daily experiences in the classroom (Thomas et al., 2015). Even where contemporary technologies are used, pedagogies predominantly replicate traditional teaching approaches (Kearney et al., 2015; Zhang, 2010). Further, although technological innovations have meant that workplaces are producing more and lives are becoming easier, related productivity gains are not widely replicated within schools (Chatterji, 2017). This age of dramatic scientific and technological advance is also characterised by rapid obsolescence (Powell & Snellman, 2004), which poses a challenge to the institutional ways of thinking and operating in schools.

The argument for rethinking and reinventing schools for a new paradigm of education (Aslan & Reigeluth, 2013) moves beyond the use of technology. As Hargreaves (1999) reasons,

> Schools in their traditional form have been patterned on the factory system. For over 150 years, schools have effectively socialised the young to the world of employment in the industrial era by age-graded classes of children following lessons punctuated by bells. As the era passes, the schools will have to change. (p. 46)

In this sense, it is not only what is taught (curriculum) and how it is taught (pedagogy) that are in question, although these factors are significant, as will be outlined in the next section. Rather, an important aspect of the need for innovation in schools lies in the organisational and institutional aspects of schools. According to Resnick at al. (2010),

> Nowhere is the challenge of innovation greater than in the education sector, where centuries old practices of teaching are embedded in political and organisational structures which are resistant to new ideas – even in the face of growing evidence that the traditional ways of working are not paying off. (p. 286)

In regard to the systemic organisational features of schools that are outdated and problematic in achieving innovation, Mehta (2013) contends that schools are organised according to bureaucratic logic rather than professional logic. In this view, schools administered according to principles of managerial control and standardisation, with power concentrated at the top and the workers (teachers) at the bottom seen as largely interchangeable. Au (2011) terms this the "factory production model of education" (p. 26), which he argues continues to see educational management and planning based on managerial and social efficiency via standardised curricula and teaching methods, with the aim of students meeting pre-determined standards and objectives. This contrasts with the professional model in which work is viewed as non-routine and requiring high levels of skill and expertise.

Reigeluth and Karnopp (2013) discuss how this outdated approach is more suited to the industrial and manufacturing age than the information and innovation age, arguing that as an aspect of both the hidden and explicit curricula it restricts the innovation education aims required of contemporary schooling. For example, whereas previous economic and societal mechanisms were served by features of standardisation such as mass production, mass communication, and mass marketing, modern economic and social practices are based on customisation and personalisation. An example of the latter is the user experience algorithms used by business and social media to direct purchasing decisions based on personal habits and preferences. However, Reigeluth and Karnopp (2013) argue that schools rarely feature customisation:

> Students in the same class are typically required to learn the same things at the same time and rate. Also, all teachers have typically received the same professional development at the same time, regardless of whether they have already learnt it or whether the training was relevant to their needs.… Standardised tests tend to assess all students in a given grade on the same competencies at the same time. (p. 9)

Reflecting Resnick at al.'s (2010) assertion that political influences embedded in the organisation of schools impede innovation, various scholars have argued that even government policy initiatives ironically aimed at achieving change or reform inadvertently work to inhibit innovation in schools. As will be outlined in Chapter 2, education reform movements in many countries have been grounded in market-based principles that have had the paradoxical anti-innovation consequence of increased standardisation and accountability being used to stimulate improvement and growth across school systems (Sahlberg, 2006). That is, education policymakers are failing to "recognise that their policy mandate and their accountability prescription are out of sync" (Bosco, 2010, p. 5) by simultaneously speaking the rhetoric of innovation and risk-taking while enacting policy settings to achieve "excellence" via such things as centralised testing, which negatively impacts innovative practices (Smith, 2006). As a means of achieving widespread improvement in academic results "instead of fostering creativity and ingenuity, more and more school systems have become obsessed with imposing and micromanaging curriculum uniformity" (Hargreaves, 2003, p. 1). Not only is this seen as inhibiting the innovative potential of schools as organisations, "accountability requirements have been a serious inhibiting factor in the development of innovative capability of students" (Bosco, 2010, p. 5).

Despite the widespread policy discourse regarding education for innovation, there is limited contemporary literature that explores what innovation essentially means in a school context, particularly outside the framework of technology-enhanced learning. This is despite the expectation that teachers, and especially school leaders, should be innovative in their practices. For instance, according to the Australian Institute of Teaching and School Leadership (AISTL, 2015), a key area of professional practice for school leaders is leading and managing innovation and change. This means, for example, that principals in Australia are required by their standards of accreditation to "identify the need for innovation and improvement" and to "embed a culture of continuous improvement, ensuring research, innovation and creativity are core characteristics of the school". This is problematic and arguably difficult to achieve while innovation as a concept in school education remains vague.

1.4 STEM and Schools

A central aspect of the call for schools to embrace innovation is to equip students with the skills they need in an "innovation economy" (Clark et al., 2018), where innovation in industries fuelling economic and social advancement is largely derived from advances in the STEM disciplines (Corlu et al., 2014). In this environment, innovation, creativity, and collaboration are considered key competencies to develop in students (Fullan & Langworthy, 2014), and skills in STEM are recognised as paramount for future success and prosperity (Education Council, 2015; English, 2018; Marginson et al., 2013; OECD, 2016b,c; Prinsley & Johnstone, 2015).

An increasing number of jobs at all levels already require STEM knowledge. US statistics since 2009 have shown that jobs growth in STEM occupations is double that of other occupations, and that STEM occupations required the "highest educational requirements" (Fayer et al., 2017). In Australia too, jobs growth in STEM fields exceeds other occupational categories (Australian Bureau of Statistics, 2014). In addition, STEM jobs require highly skilled and educated graduates, which has been cause for concern in Australia, given that Australia's performance at school level in mathematics and science has been declining (Thomson et al., 2017).

The Australian Education Council (2015) in their report *National STEM School Education Strategy 2016–2026* (Education Council, 2015) makes the case for a national focus on STEM in school education to ensure that "all young Australians are equipped with the necessary STEM skills and knowledge that they will need to succeed" (p. 4). The STEM priory for Australian schools is made explicit:

> School systems have a responsibility to ensure that all young people have a fundamental level of STEM literacy that enables them to engage with, and succeed in, the world beyond the school gate. Building foundational STEM knowledge needs to start from early childhood and continue throughout primary and secondary schooling. (Education Council, 2015, p. 5)

Further, in a 2017 report, *Australia 2030: Prosperity Through Innovation*, Innovation and Science Australia called for a minimum national requirement for teacher professional learning in STEM to ensure ongoing development in STEM disciplines. They also called for broader metrics than PISA and NAPLAN to measure achievement in STEM disciplines. Even more recently, the Australian Education Council (2018) in its final report for the STEM partnerships forum called for primary schools to be included in the STEM education narrative:

> Governments and industry should work together to focus the narrative for primary and secondary students on how STEM skills and knowledge can solve real world problems. Having been motivated by real world problems, students should be introduced to the applicable subjects, skills and jobs that will afford them career flexibility as they contribute to meeting the needs of our future

> society. There should be particular effort to engage student cohorts underrepresented in STEM fields. (p. 15)

This imperative was also emphasised by Timms et al. (2018) in their report *Challenges in STEM Learning in Australian Schools*, which called for early intervention and access in STEM learning for Australian students. The theme of engaging younger learners to build foundational skills in STEM has been reinforced in the US, with the federal *Strategy for STEM Education* (National Science and Technology Council Committee on STEM Education, 2018) stating that younger learners should begin developing computational thinking and digital literacy skills.

However, debate lingers about the pedagogical approaches that are best suited to the integration and teaching of STEM subjects in schools (Breiner et al., 2012; Lamberg & Trzynadlowski, 2015). There is also debate about the capacity of our education systems, which feature standardised assessment, rigidity in curriculum, and attachment to traditional teaching methods, to accommodate innovative or even simply effective STEM education at the school level (Williams, 2011). Essentially, "STEM represents a way to think about curriculum change" (Herschbach, 2011, p. 98), and as Wilson (2020) argues, effective STEM teaching and learning require innovative pedagogical practices that rely on innovation and experimentation by teachers. In this sense, it has been claimed that STEM education can be considered an educational innovation in itself, "with various instructional models and emphases that are shaping reform in many educational systems" (Holmlund et al., 2018, p. 2).

Schools, then, are being called on to engage in innovative pedagogical practices to produce the future STEM innovators of tomorrow. However, despite the widespread policy discourse surrounding the imperative of STEM education and innovation in schools, there has been little research on the enablers and inhibitors of school innovation and innovative teaching, particularly in relation to STEM education.

1.5 The Research Problem

In an era of economic competitiveness defined by a nation's ability to innovate, governments look to schools to produce a skilled and innovative future workforce. To deliver on this, schools need to change the ways they teach. Such changes can also be thought of as innovation; innovative approaches to teaching (innovative teaching) and innovation in schools (innovative school management and leadership). However, what exactly does innovation mean in a school context? How do schools, in their institutional and regulatory environments, innovate?

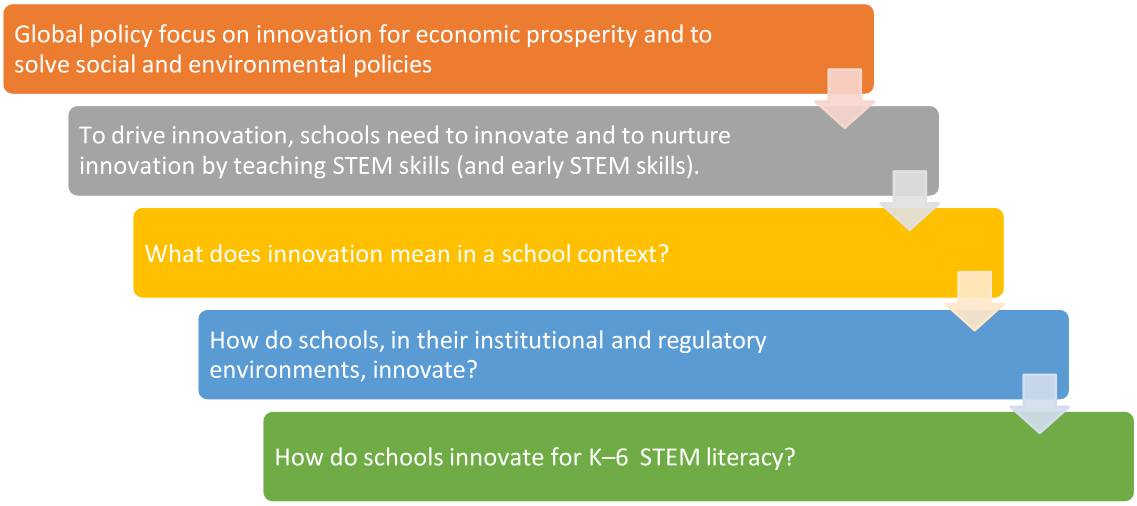
Further, among the skills deemed necessary for an innovative future workforce, the most strongly represented in international contemporary innovation policies are STEM skills (OECD, 2016b, 2016c), with increasing student participation in STEM "a primary component of policy measures to strengthen education for innovation" (OECD, 2016c, p. 3). Additionally, as will be outlined in the literature review (Chapter 2), there is a gap in the literature about innovative teaching and innovative school management and leadership in relation to STEM education, particularly in the K–6 context. The K–6 context is significant, given the recent calls for early exposure and intervention in STEM learning to develop STEM literacy (see 1.8.3). Hence, STEM education is an important context to investigate innovative teaching.

As encapsulated in Figure 1.1, there are five components to the research problem of this study. That is, (1) there is a global policy focus on innovation and (2) a recognition that in order to drive innovation, schools need to innovate and nurture innovation in students. Further, (3) there is need for a better understanding of innovation in a school context and also (4) an understanding of how schools are able to innovate within the institutional and regulatory frameworks that they operate. Finally, (5) there is a need to determine how schools can innovate for STEM literacy in the K–6 context. In seeking to identify how schools can allow for innovative teaching and leadership to produce the STEM innovators of tomorrow, I address the following three research questions.

1. How is school innovation defined by experts in the field?
2. What are the factors that foster and limit innovation in schools?
3. What factors enhance or prevent innovation in K–6 STEM learning?

Figure 1.1

Summary of the Research Problem



The complexity of this research problem, which exists at the intersection of political ideology and educational philosophy, must be acknowledged. At the heart of the problem is the question of the purpose of modern education, the moral and ethical ideas that exist within it, and the tensions that these create for innovation in schools. There is the argument that within the modern global, neoliberal socioeconomic and sociopolitical paradigm schools have moved from places of liberal education with democratic ideals to become engines to power the global economy by producing highly skilled workers for the 21st century (Gary, 2017). It is from this neoliberal paradigm that the international drive for STEM education in schools has emerged (Carter, 2015, 2017; Weinstein et al., 2016).

As will be noted in Chapter 2, this same thinking has influenced the ways that schools are governed and administered, resulting in the "commodification of schooling" (Sturrock, 2021, p. 1215), with structures of performativity, accountability, and surveillance grounded in narratives of efficiency, excellence, and standards (Hall & Pulsford, 2019). In addition to tensions impacting innovation in schools concerning the paradox of *marketisation* and *standardisation* (see Section 2.3), the modern neoliberal ethics of schools are concerned with a moral imperative towards the "effectiveness" of teaching and learning where "the teacher becomes a producer of 'human capital' and thus her level of production must be measurable" (Thompson & Jones, 2021, p. 94). This has worked to limit teacher autonomy and professional decision making (Biesta, 2013, 2015, 2017; Giroux, 2012; Pulsford, 2019), which is problematic if "effective" STEM teaching and learning requires innovative pedagogical practices and experimentation by teachers (Wilson, 2020).

These tensions between neoliberal purposes and control are highlighted in this study. However, as outlined earlier, this study is also concerned with identifying the factors that facilitate and constrain innovation in schools and innovative teaching and leadership of K–6 STEM. This research has examined the perceptions of teachers and school leaders, as well as experts in the field, about school- and system- level factors influencing innovation in schools. This thesis aims to define a contemporary understanding of innovation that can be applied to teaching in schools.

1.6 Study Design

In addressing the research questions, the study used a research design underpinned by a pragmatic sociocultural perspective (Glăveanu, 2021; Schoen, 2011; Somekh, 2007). Although phase one of the research used Delphi method, and phase two used narrative inquiry, the overarching research approach applied in the study is that of narrative inquiry, wherein narrative thinking is used as a frame of reference and a way of reflecting during the entire research process (Moen, 2006).

Previous studies have used findings from Delphi studies have used narrative inquiry in combination with the Delphi method (Engels & Kennedy, 2007; Kennedy, 2004; Isobel, 2011). In this study, the findings from the Delphi research allowed for the application of a contemporary consensus understanding innovation when unpacking the STEM learning narratives from phase two and were thus integral to the narrative process. Importantly, the first two research questions needed to be answered in order to address the final question. That is, a contemporary understanding of innovative teaching and innovation in a school context needed to be understood before the factors that enhance or constrain innovative K–6 STEM learning could be examined via narrative inquiry. Hence, the investigation of the first two questions (which guided the first phase of the research) directly informed the investigation of the third question (which guided the second phase of the research).

1.7 Significance of the Study

The primary outcome of the study will be an understanding of innovation in schools and the factors that enable or inhibit innovative teaching and innovative school leadership practices involving STEM education in the primary (K–6) context. This will inform policy and help teaching practitioners in the development and application of innovative approaches to STEM education.

The focus of the study is the teaching and leadership of K–6 STEM education programs. The research is significant because of the increasing value attributed to building students' foundational STEM knowledge in primary schools (Education Council, 2015, 2018; National Science and Technology Council Committee on STEM Education, 2018; Timms et al., 2018), and because there is a lack of research in this space. Also, there is widespread acknowledgement that education must change from traditional teaching practices to those that develop skills (including STEM) to prepare students for an innovation economy. This study aims to fill the gap in research by both defining innovation in schools in terms of teaching and leadership, as well as in terms of the development of STEM skills in K–6 education.

1.8 Definitions and Concepts Used in the Study

1.8.1 Innovation

Chapter 2 outlines the history and evolution of the term innovation and how it has come to be expressed in business and social sectors. It goes on to define innovation as it applies in a school context, including innovation in teaching and school leadership. For the purposes of this study, the term *innovation* is understood in reference to the OECD "Oslo Manual" (OECD/Eurostat, 2005), which defines innovation as implementation of a new or significantly improved product (good or service), process, method or practice. Further, as will be made clear in the following chapters, this study recognises that in addition to the elements above, innovation can be considered an outcome (Crossan & Apaydin, 2010), a mindset (Kahn, 2018), and a human action (Montenegro et al., 2019).

1.8.2 Innovation Skills

This study uses the definition of innovation skills offered by Innovation and Science Australia (2017). These include digital skills, interpersonal skills, creativity, problem-solving ability, entrepreneurial skills, as well as skills in Science, Technology, Engineering, and Mathematics (STEM).

1.8.3 STEM, STEM Learning Innovation, and STEM literacy

STEM in this study refers to the study of Science, Technology, Engineering, and Mathematics as an integrated "meta-discipline" (Kennedy & Odell, 2014, p. 246). In short, the integration of the disciplines equals more than the sum of its parts. As such, interpretations of STEM that include added disciplines, such as the inclusion of A for Art in STEAM (Maeda, 2013), are all considered under the STEM umbrella in this research.

Importantly, the phrase "STEM learning innovation" is used throughout the study. STEM learning innovation is a concept coined by English (2018) and has been interpreted in this study to include innovative approaches to STEM, with the aim and potential to produce innovation skills in students. As outlined by English, the concept of STEM learning innovation recognises that (1) learning innovation involves the processes of generating new knowledge and ideas that can be applied to solving novel problems, and (2) integrated STEM is an ideal vehicle for fostering disruptive innovative thinking in students, and STEM learning is a means by which education can adapt to a disruptive world.

As outlined in earlier in this chapter, policy reports have highlighted the importance of fostering foundational STEM skills in young learners and STEM literacy among primary age students (Education Council, 2015; 2018; National Science and Technology Council Committee on STEM Education, 2018). Jackson et al. (2021) define STEM literacy as the ability to apply concepts from science, technology, engineering, and mathematics to solve problems that cannot be solved using a single discipline. Mohr-Schroeder et al. (2020) define STEM literacy as

> the dynamic process and ability to apply, question, collaborate, appreciate, engage, persist, and understand the utility of STEM concepts and skills to

> provide solutions for STEM-related personal, societal, and global challenges that cannot be solved using a single discipline. (p. 33)

Falloon et al. (2020) argue that STEM literacy is the goal and purpose of STEM education and describe it as the combination of discipline knowledge and "capabilities, skills and dispositions, aligned with the needs of young people functioning productively and ethically in dynamic, complex and challenging future work, social and political environments" (p. 1). In this study, early STEM literacy refers to the exposure and intervention in STEM learning to develop foundational STEM literacy in the K–6 years.

1.8.4 Education Systems and School Systems

In order to learn about how innovation and STEM learning is considered in light of different policies, practices and traditions affecting schools, this study gained insights from the shared and contrasting experiences of educators and experts in different countries and economies. As such, the terms *education systems* and *school systems* are used throughout this thesis. An education system is defined as the network and coordination of economic and social elements and factors that constitute education (from early childhood to university) within a federal or state government jurisdiction. Such elements include legislation, public funding, institutions (schools, universities etc) and organisational factors (such as the progression of learning K–12), curriculum and pedagogy, assessment regimes, staffing structures, professional bodies, and infrastructure, as well as cultural and political influences. A school system is an entity maintained by policies, practices, and resources that apply to a group of schools within and directed by a wider education system (OECD, 2010b).

1.8.5 Neoliberal Education Reform, GERM, and the Pressures of Standardisation

As discussed earlier in this chapter and will be further outlined in Chapter 2, the neoliberal sociopolitical paradigm governing schools in the West forms part of the complexity of this study. According to Sahlberg (2006), the education reforms that many countries have been undergoing in recent years in order to provide their citizens with knowledge and skills for a dynamic knowledge-based economy have been increasingly embedded with "market values like productivity, effectiveness, accountability and competitiveness" (p. 262). That is, many governments have introduced market mechanisms into their education systems with the aim of improving the quality of education and of promoting innovation in education "within classrooms, in governance and management, in content, in information and delivery systems" (Lubienski, 2009, p. 12). As will be discussed in Chapter 2, the *marketisation* of school systems has led to the paradoxical consequence of increased *standardisation*, with the resulting accountability used as a means of improvement and growth across school systems. Sahlberg (2006) uses the term Global Education Reform Movement, or GERM, to describe the emergence of this education reform phenomenon, which he refers to as the new global orthodoxy in education policy.

The term *pressure* has been used in previous research to describe the impact of accountability measures and standardisation on teachers and schools; for example, the demands that teachers and school leaders feel in teaching a standardised curriculum to achieve target results in standardised tests (Hargreaves & Shirley, 2008; Metz, 2003; Looney, 2009; Rubin, 2011; Schoen & Fusarelli, 2008; Sleeter & Carmona, 2017) and the difficulties presented by regulatory and institutional standardisation in implementing and sustaining innovation in schools (Fink & Brayman, 2004; Giles & Hargreaves, 2006). *Pressure* appears in this sense at times throughout the study in the Delphi panel commentary, in the words of participants in the narrative case studies, and consequently in the discussion of the findings.

1.9 Organisation of the Thesis

This thesis has six chapters. In Chapter 1, the background and purpose of the study has been discussed, including an overview of the interaction between global policy priorities in innovation and STEM and STEM education in schools, the problem area, the aim of the study, the research questions, and the significance of this study. Chapter 2 includes a thorough review of literature on topics central to the study, including a historical and current review of the most important and critical aspects of innovation and STEM in relation to the research problem. It draws from the body of work that includes innovations theory, innovation in an educational context, and innovation as it relates to school reform and education policy, as well as STEM in the context of innovative teaching and primary education. Chapter 3 presents the methodology used in this study. It describes the pragmatic sociocultural epistemological and theoretical foundations informing the research design, outlining the overarching narrative inquiry approach and detailing the Dephi method applied in the initial phase to extrapolate a definition of innovation in schools and to inform the second phase of the research. Ethical considerations, methodological limitations, and issues of validity and reliability are also discussed.

Chapter 4 outlines the findings from phases one and two of the research presented in narrative format. It begins with a prologue that sets the scene by presenting the findings of the Delphi study from phase one followed by stories which encompass the narrative of innovative STEM in primary schools. Chapter 5 involves a “restorying” of the findings to describe insights about innovative K–6 STEM education in relation to the research questions and the literature, highlighting the “commonplaces” uncovered (Connelly & Clandinin, 2006). That is, the findings are re-storified to produce a final narrative, and to unpack and illustrate a deep understanding of school innovation using the stories of K–6 STEM. The final chapter, Chapter 6, focuses on the conclusions and contributions of this study. The research findings are reaffirmed, highlighting the ways in which the study has contributed to a deeper understanding of innovation in schools and of the enablers and barriers to innovation in K–6 STEM learning.

1.10 Conclusion

This chapter has outlined the background and the purpose for studying the barriers and enablers to innovative teaching and leadership of STEM learning in K–6 schools. It explained how the global policy priorities of innovation and STEM have worked to form a call to action for schools to produce future STEM innovators, and it discussed the difficulties associated with this in regard to the current status of innovation and STEM learning in schools. The chapter defined the research problem and questions and outlined the significance of the study in developing a better understanding of innovation in a school context and the institutional, regulatory, and other influences that can enhance or prevent innovation in K–6 STEM learning.

The next chapter provides a review of the literature on topics central to the study, including innovations theory, innovation in an educational context, innovation as it relates to school reform and education policy, and STEM in the context of innovative teaching and primary education.

Chapter 2

Review of the Literature

Chapter 1 outlined the background and purpose for studying innovation in schools, particularly for K–6 STEM learning. It provided an overview of the interaction between global policy priorities in innovation and STEM education in schools, the problem area, the research questions, and the significance of this study. The aim of this literature review is to reveal the most important and critical aspects of innovation and STEM education in relation to the research problem. It draws from the body of work that includes innovations theory, innovation in an educational context, examination of innovation as it relates to school reform and education policy, and STEM education in the context of innovative teaching and primary education.

This review begins by outlining the history and evolution of the concept of innovation and how it is defined in the literature. It then explores the various areas of the literature in which innovation relates to school education: learning, schools, teaching, teachers, school leadership, school culture, disruptive innovation, and STEM education. This leads to an outline of literature dealing with the emergence of STEM education and STEM integration, along with the body of work addressing the systemic and structural school features that can impede the teaching of K–6 STEM. Following this is a review of literature addressing innovation and school reform, including the macro-level features (including educational policy, legislation, and systemic factors) that can influence innovation in schools. The chapter concludes by identifying the gaps in knowledge on innovation in schools and the factors that influence innovation in K–6 STEM, outlining areas of suggested research.

2.1 Innovation

> Innovation is everywhere. In the world of goods (technology) certainly, but also in the realm of words: innovation is discussed in the scientific and technical literature, in social sciences like history, sociology, management and economics, and in the humanities and arts. Innovation is also a central idea in the popular imaginary, in the media, in public policy and is part of everybody's vocabulary. Briefly stated, innovation has become the emblem of the modern society, a

> panacea for resolving many problems, and a phenomenon to be studied. (Godin, 2008b, p. 5)

According to Rogers (2010), the eminent theorist and sociologist who originated the diffusion of innovations theory in 1962 and coined the term "early adopter", an innovation is an idea, practice or object that is perceived as new. For Crossan and Apaydin (2010), who emphasise the value-added aspect, an innovation is both a process and an outcome, meaning there is an intended benefit. Utterback (1971) was a pioneer in modelling innovation as a managerial process in terms of idea generation, problem solving, implementation, and diffusion, and various frameworks have built on his work to describe the process of innovation used within organisations (Salerno et al., 2015). Kahn (2018), like Crossan and Apaydin (2010), defines innovation as an outcome as well as a process, where an outcome can be, among other things, an innovation in product, process, or organisational or business model. Kahn adds a third dimension to innovation, describing it also as a mindset, which addresses both the internalisation of innovation by individual members of an organisation and the supportive organisational culture that allows it to flourish. In this vein, Montenegro et al. (2019) describe innovation as a human action, and more specifically, a creative intellectual action that requires experimentation and the application of theoretical and practical knowledge to solve a problem.

As noted by von Schomberg and Blok (2018), "the concept of innovation has traveled through a rich history of different meanings" (p. 4668). Since the 20th century, innovation has usually been discussed in scientific, technical and economic literature, and it is most predominantly associated with technological advancement and economic progress. However, according to historical researcher Godin (2015), for the previous 2,500 years, innovation had nothing to do with economics in a positive sense, but instead had political connotations and was meant to introduce change to the established societal order that could ruin, trouble, and dissatisfy the state (von Schomberg & Blok, 2018). Godin (2008a, 2010) further points out that until the industrial revolution established innovation as synonymous with research and bringing a new technology to market, to be considered an innovator was tantamount to being named a heretic (see also Schumpeter, 1934). In fact, King Edward VI of England (reigned 1547–1553) issued *A Proclamation Against Those That Doeth Innovate*, and "pejorative representations of innovation (any kind of innovation) would remain the rule until the second half of the nineteenth century and early twentieth century" (Godin, 2010, p. 6). In stark contrast, in the 21st century the language around innovation used by business and governments is coined in hopeful terms, and innovation is considered a process essential to success (Johnson, 2001). Von Schomberg and Blok (2018) explain:

> The history of innovation teaches us that the meaning of innovation shifts according to the dominating worldview of the context in which it emerges. In times when the ideal of maintaining stability is most prominent, innovation is considered a threat to society and thus widely labeled as a pejorative concept. As the ideal of maintaining stability is replaced by the ideal of achieving progress, both within and beyond technology, innovation gradually starts to have a positive connotation. (p. 4676)

Indeed, scholars in various fields refer to the modern era as the "age of innovation" (Araya & Peters, 2010; Corlu et al., 2014, Goldberg, 2018; Janszen, 2000; Krinsky, 2012; Vineyard et al., 2012; von Schomberg & Blok, 2018), and, as discussed in Chapter 1, over the past three decades innovation has become a policy priority internationally. As also referred to in Chapter 1, in establishing a contemporary understanding of the broad concept of innovation for the purposes of this study, the OECD definition is used. In its 'Oslo Manual' the OECD defines innovation as "the implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relation." (OECD/Eurostat, 2005, p. 146)

2.1.1 Innovation and Learning

As stated earlier, innovation arose in the literature as a science and economic principle after the industrial revolution. In fact, Shumpeter (1939), the theorist known as the pioneer of innovation in its modern usage, defined it as "doing things differently in the realm of economic life" (p. 84). In the late 1960s and early 1970s, however, the concept of "social innovation" arose, recognising the distinction between an innovation to produce a product or technology in an economic sense and an innovation that is applied in a social or organisational environment. As Taylor (1970) put it,

> A new mousetrap requires no great revolution in anyone's lifestyle or identity; the consumer simply substitutes the new mousetrap for the old one and life goes on unchanged. But a new social form is not introduced so easily. An innovative

> kind of school, a new way of dealing with poverty, a new procedure for socialising delinquents, a new technique for rehabilitating the schizophrenic – all are likely to disrupt complex and valued roles, identities, and skills. (p. 70)

"Social innovation" evolved over time to mean renewal based on social needs (Drucker, 1985), and it has led to scholarly study of more holistic approaches to innovation that now consider both social and economic consequences (Van der Have & Rubalcaba, 2016). It is within this branch of study that innovation has been linked to workplace or organisational learning (Darsø & Høyrup, 2012).

Numerous studies have explained the relationship between workplace or organisational learning and innovation (Cohen & Levinthal, 1990; Coombs & Hull, 1998; Hage, 1999; Hall & Andriani, 2003; Kogut & Zander, 1992; Leonard-Barton, 1995; Nonaka & Takeuchi, 2007; Nooteboom, 1999; Sørensen & Stuart, 2000; Stata, 1989). Beckman and Barry (2007) outline their model of innovation as a learning process within organisations that evolved through two streams of thought: design and learning. That is, innovation in a workplace is linked to the problem-solving design process and to the learning cycle in experiential learning theory. The innovation-as-a-learning-process model arose from "second generation" design theories and methods that focused on design as a social process. These theories accommodated a less top-down view of design as solutions provided by an expert, to a view of design as a collaborative problem-forming, problem-solving process involving a broader range of people. Where innovation is viewed as a learning-process, the innovation process is connected to a learning cycle where teams in workplaces responsible for innovation are also learners that experience/observe; reflect/frame/reframe data collected from observations into insights; define imperatives in terms of design principles or value propositions; and produce and test solutions. Høyrup (2010) also describes this employee-driven innovation as a mode of learning, where innovation follows a learning process that emerges from the social context of the workplace by observing others, learning through the sharing of experience and knowledge, learning through mentoring situations, learning from mistakes, and learning through individual or collective reflection.

This design-thinking approach to innovation as a learning-process has not been widely studied in relation to teachers as actors in school workplaces. Bakkenes et al. (2010) studied the learning activities teachers deploy in the context of educational innovation and the learning outcomes and learning activities teachers engage with "when confronted with educational innovation" (p. 534). They uncovered the actions and learning outcomes of teachers that were required to implement a way of teaching (active and self-regulated learning) other than by using design thinking and thus learning from the process of designing innovative teaching. That is, they studied teacher learning in the context of innovation rather than as a process of innovation.

Westbroek et al. (2019) reviewed various studies from 1988 to 2009 in which teachers worked in collaborative design teams to create new curricular materials such as courses or lessons in co-operation with each other and often also with experts from the educational design, educational research, and educational content domains. They found that collaborative curriculum design positively affects the professional development of teachers – "teachers are explicitly learners" (p. 50) – and can also result in curriculum innovation. Although no single model was recommended by Westbroek et al., the design (and learning) processes outlined could be applied to school-based collaborative design settings in which teachers are active agents and initiators of change, and who cooperate to set goals and improve their practice. While this study is useful, it is limited by its time frame and restriction to curriculum design.

2.1.2 Innovation and Schools

Despite the prominence of innovation in current discourse, there has been little research that addresses issues of innovation as they apply specifically to school education and innovative teaching. The OECD (2016) report, *The Innovation Imperative in Education*, claims that the Oslo Manual definition can also be applied to education "with small modifications" (p. 16), and it extends the definition to "educational organisations" including schools, universities, training centres, and education publishers. Much of the literature on innovation and education applies to higher education, particularly regarding innovative pedagogy (Chandra et al., 2021; Jaskyte et al., 2009; Nicolaides, 2012; Reisman, 2016; Walder, 2014). Serdyukov (2017) defines educational innovation broadly, in terms of both school and higher education in combination:

> In education, innovation can appear as a new pedagogic theory, methodological approach, teaching technique, instructional tool, learning process, or institutional structure that, when implemented, produces a significant change in teaching and learning, which leads to better student learning. So, innovations in education are

> intended to raise productivity and efficiency of learning and/or improve learning quality. (p. 8)

Much of the research focusing on innovation in schools builds on the study of innovation in organisations and refers to innovation as a concept of improvement in the context of greater education reform. For example, following from the work of Senge (1990) relating to organisational change, literature began to emerge that talked about schools in increasingly knowledge-using societies as needing to become “learning organisations” in which where processes and structures would become innovative in the sense that they were more localised and contextualised (Giles & Hargreaves, 2006). The language around this involved continual (teacher) learning, improvement, cultural change, and transformational leadership as features of innovation, rather than as teaching for the development of skills for an innovative future (Darling-Hammond, 2008; Fullan, 2002; Hallinger, 2003; Resnick et al., 2010; Senge et al., 2012; Silins & Mulford, 2002). That is, the studies examined innovation as a means of achieving higher quality teaching, or with the “moral purpose” (Fullan, 2002) of closing the gap between higher performing and lower performing students. In this sense, innovation is viewed as adapting current practices to see improved results as measured by traditional means (for example achieving an improved test score), rather than as disrupting the status quo to achieve new and innovative approaches and solutions that change the face of education.

A more comprehensive description of innovation in schools has been offered by Hargreaves (1999), for whom it is a process undertaken by imaginative and responsive schools when encountering problems and challenges or when establishing a different way of doing something that has become staled by custom or tradition. Similarly, in their framework for curriculum innovation, Tytler et al. (2011) define innovation as the process of assembling and maintaining a novel alignment of ideas, practices, and actors to respond to issues and/or to pursue a vision. Interestingly, they note, “What is innovative at one school or school cluster is not necessarily innovative at another” (p. 22). The definitions given in this section are useful, even though much of the associated research was conducted some time ago. An exploration of these definitions in the current context should provide a fresh understanding of innovation as it applies specifically to schools.

2.1.3 Innovative Teaching

From the limited research regarding the term *innovative teaching*, this study adopts the definition of Ferrari et al. (2009), for whom innovative teaching is the implementation of new methods, tools, and content that can benefit learners and their creative potential; in other words, it is the practice of teaching for creativity. This reflects the definition of innovation as both a process and an outcome (Crossan & Apaydin, 2010), and it aligns with the view that modern education should be shaped by innovations and train students to produce innovations (Mirzajani et al., 2016), and also foster student development of the complex transdisciplinary skills required in the modern age (Sias et al., 2016). Jeffrey (2006) similarly describes innovation in teaching and creative pedagogies in terms of the impact and "creative agency" in student learning. Also, Kozma and Anderson (2002) outline innovative teaching as emerging practices that involve changes in what teachers and students do and learn in the classroom and that provide students with skills and competencies for lifelong learning in the knowledge and information economy. This definition is also supported in Langworthy et al.'s (2010) international research on "educator's adoption of innovative teaching practices and the degree to which those practices provide students with learning experiences that promote the skills they need to live and work in the 21st Century" (p. 107). Sawyer (2006) also notes that one of the challenges of our school systems, which are typically geared for teaching for the industrial rather than knowledge economy, is for "schools to connect individual learning for creativity to social and organisational creativity and learning" (p. 46).

Other studies adding to the knowledge base of innovative teaching have focused on specific teaching practices such as active learning (Zhu et al., 2013), constructivist teaching (Heaysman & Tubin; 2019), self-directed learning (Voskamp et al., 2020), coding (Wong et al., 2015), and technology-enhanced or mobile learning (Burden et al., 2019; Chou et al., 2019; Ilomäki & Lakkala, 2018). The research undertaken in this study contributes to the understanding of innovative teaching in a broader sense that can be applied across a range of pedagogical practices.

2.1.4 Innovative Teachers

Much of the literature around innovative teaching and innovation in schools has focused on the traits, competencies, and behaviours demonstrated by teachers. Cumming and

Owen (2001) outline the strengths of teachers they describe as innovative: personal attributes (altruism, creativity, and passion); skills (applied learning, standard setting, and change management); knowledge (innovation, pedagogy, and professional development); values (total commitment to those they teach; willingness to share their knowledge, skills, and strategies with others; and an insatiable desire to improve their own practice and "reinvent" themselves in response to new demands, challenges, and opportunities); and strategies (creation of alliances, marshalling of resources, and identification of advocates). Messmann and Mulder (2011) describe teachers' "innovative behaviour" as adapting ideas, building a strategy of action, assessing through reflection and evaluation, adjusting the innovation, and finding allies. Nadelson and Seifert (2016) studied teachers' professional behaviours associated with their propensity to adopt innovative curricula and engage in innovative instructional practices. The authors found knowledge seeking, embracing change, exploring opportunities, and acting on a sense of responsibility as the behaviour traits that stood out.

According to Holdsworth and Maynes (2017), innovative practices in schools are strongly affected by the attitudes and beliefs of teachers. Ferrari et al. (2009) found that teachers need to value, understand, and possess skills in innovation and creativity in order to promote innovation in education. Savina (2019) found there are psychological as well as professional barriers inherent to individual teachers who show resistance to innovation. Psychological barriers can be related to values of traditional conservatism and stereotypical thinking, and professional barriers can be a tendency within the teacher to be reproductive rather than creative in their teaching practice after a level of experience is achieved. In addition, Savina reports that some teachers view new pedagogical activities as temporary tendencies that will lose relevance over time. Holdsworth and Maynes (2017) argue that what could be seen as reluctance or inflexibility may in fact be an issue of congruence with teacher beliefs, and therefore innovations can be successful when teachers have opportunities to implement them in line with processes that are best suited to their own abilities. Similarly, Wallace and Priestly (2011) report that when innovations are imposed on schools, teachers who can transform them according to their own beliefs are more likely to sustain new practices in their classrooms.

In relation to innovation as a personal factor or an attribute of an individual teacher, a relationship with entrepreneurism is a natural and logical association because entrepreneurship is a "driving force of change and innovation, introducing opportunities to achieve efficient and effective performance in both public and private sectors" (Yemini et al., 2015, p. 3). Yemini et al. (2015) highlight the entrepreneurial activities and traits of some school principals, labelling them as "institutional entrepreneurs", which refers to their ability to comply with institutional demands (for example, improving academic achievement) and regulations while also taking proactive roles in advancing initiatives and changes that reflect their own interests and respond to the needs of their schools. Research by Borasi and Finnigan (2010) linked "social entrepreneurship" and teaching, and they outline entrepreneurial attitudes and behaviours that can be applied to school teachers, school leaders, and leaders in education generally. Their case studies found several common features among "entrepreneurial educators": being driven by a vision; relentlessly innovating; being alert to and ready to seize opportunities; working beyond resource constraints; networking; quick and timely decision-making; creative problem-solving; and confident risk-taking. Both studies examined innovation and entrepreneurship in relation to the individuals, primarily school leaders, but neither mentioned STEM or teaching behaviours that foster creative learning and the development of skills for innovation in students.

In their literature review, Thurlings et al. (2014) found that the factors influencing teachers' innovative behaviours fall into two main categories: factors within the individual, such as self-efficacy, attitudes, and beliefs; and external factors, including support from colleagues and managers, organisational culture, and facilities and resources. With regard to the internal factors, the authors suggested that educational organisations that want to increase innovative behaviour should select or create human resource management instruments intended to identify teachers with the personal qualities that lead to more innovative behaviour. However, the findings of the study are applied to educational organisations, including higher education, and not specifically schools. Further, the research referenced by Thurlings et al. in relation to external factors almost exclusively involved the study of innovative behaviour in organisations other than schools. The studies in schools that were cited did not specifically address the idea of "innovation," but looked at ICT integration and teaching for learner autonomy.

The authors also state that while individual and external factors have been studied in isolation, no holistic study has been conducted into the factors that influence teachers' innovative behaviours. Langworthy et al. (2010) purported to look at the adoption of innovative practices for the development of 21st-century skills in the light of "system, school, educator, classroom and student levels" (p. 107), yet they focused in large part on ICT integration into teaching and learning.

2.1.5 Innovative School Leadership

Various researchers have found that innovative leadership is important, if not essential, to innovation in schools. A Finnish study by Vaara and Lonka (2014) found "supporting practices" that establish links between the administrative elements of a school and classroom teaching,

> In an innovative school the practices of teaching and learning should be in line with the organisation's leadership philosophy and vice versa … [and] this study strongly indicates that innovative design calls for innovative leadership. (p. 1634)

This idea was also examined in a Chilean study by Riveras-León and Tomàs-Folch (2020), who found that the actions of the school principal are essential for the generation of an innovative school. In particular, the democratic and participatory leadership of a principal is important in ensuring that teachers feel their opinions are valued and are considered in decision-making, and that they are deemed responsible and capable of assuming challenges. Buske (2018) also found that the principal's democratic leadership style is the strongest predictor of teachers' collective innovativeness. A study of Malaysian high schools by Pihie et al (2012) found a significant correlation between teacher perception of school principals' entrepreneurial leadership practices and innovation in schools, as did a study in Korean vocational high schools by Park (2012). Wibowo and Saptono (2018) also found in their study in Indonesian primary schools that entrepreneurial leadership directly and positively influences teachers' creativity and innovative practices.

A study by Koch et al. (2015) examined school principals' work engagement as a motivational catalyst for nurturing the creativity of teachers. They found that when principals act as role models and demonstrate enjoyment and high effort in their work, this serves as an innovation-fostering element by encouraging teachers to feel more energetic and more attached to the generation of ideas. Lawson et al. (2017) found that in "odds-beating" innovative elementary schools, principals explicitly prioritise developing and building relational trust. Schwabsky et al. (2019) also argue that leadership that cultivates collective teacher efficacy and trust is positively correlated to school innovation.

For the most part, the literature on innovative school leadership reflects the new global reform orthodoxy in education policy (Fuller & Stevenson, 2019) in terms of "transformational leadership practices", "improvement" and "effectiveness", as measured by student performance (Fullan, 2011; Hopkins et al., 2014; Lawson et al., 2017; Leithwood & Strauss, 2009; Levin, 2012). Tonkin (2016) also found that innovative principals are driven to "do things differently" and to push the boundaries of what is possible, yet these are considered within the framework of "success," "high performance" and "sustained improvement." Schoen and Fusarelli (2008) argue that the standardisation movement is incompatible with innovative leadership and innovation in schools. Santamaria and Santamaria (2016) similarly question the innovativeness of leadership practices that focus on improvement of student standardised results, instead promoting that innovative leadership

> should push the boundaries of the status quo leadership practice and further develop existing culturally responsive practices in education so these ways of leading begin to rely upon, support, and reflect local, regional and global contexts. A shift in leadership in this direction would certainly be a new idea and method, and as a result, signal innovation. (p. 1)

Section 2.3 discusses this performance-driven culture of improvement, the concept of standardisation, the global education reform movement, and how they relate to innovation in schools.

2.1.6 Innovative School Cultures

Closely linked to the issues of leadership and innovation in schools is the climate or culture of a school. Educational theorists have long considered that the distinctive culture of a school impacts the learning of its students. John Dewey (1916) described a social environment, and "the school as a special environment" (p. 22), as consisting of all the activities carried out by its members. Dewey wrote that the social environment or culture of a school is itself educative, in that as a member (teacher or student) participates they take on the "emotional spirit" of the environment, along with its purpose, methods, subject matters and needed skill (p. 26). As such, one school can be differentiated from another by the characteristics of its culture (Kallestad, 2010), including things that are influenced by leadership such as the organisation and orderliness of the school environment, and expectations of teacher behaviour and student outcomes (Creemers & Reezigt, 1999).

Chang et al. (2011) examined the relationship between creative teaching behaviours and "innovation-fostering" elements of the organisational climates in schools. The definition of creative teaching used in their study does not emphasise the fostering of innovation skills in students, but rather features "open-mindedness" and "imaginative teaching" (p. 939). The innovation-fostering elements used to examine the schools are not explained in detail, although they are narrowed down to six factors: "working conditions and learning and growing, organisational leadership and support from colleagues, education policy and work environment, equipment resources and educational opportunities, low organisational barriers, and overall organisational climate for innovation" (p. 940). Chang et al. found that innovation and "creative teaching" appear to be strongly associated with an innovative organisational climate within a school, particularly when teachers are given opportunities for professional development. A recent study by Paletta et al. (2021) made similar findings, stating that innovative teaching practices are associated with schools in which principals and teachers agree on the collaborative culture, learning climate, professional development, and instructional leadership. Here, an explicit link is made between these elements and professional learning by teachers. However, the definition of innovative teaching practices is not elaborated on, other than to say that it is linked to teacher support of the implementation of specific actions for school improvement.

Other researchers have discussed the failure to sustain educational innovations due to the lack of understanding of the need for teacher learning (King, 2014; Vermunt & Endedijk, 2011). According to Geijsel et al. (2001), who studied the implementation of large-scale innovations from a teacher's perspective, whether or not teachers develop professionally to support innovation "depends on the characteristics of the teachers themselves" (p. 133) and of the environments in which they work and function.

Moolenaar et al. (2010) found that teachers who perceive their school's climate as innovative are often guided by leaders who both display innovative behaviour themselves and occupy positions close to those of these teachers. That is, innovative leaders create a climate for innovation by sharing and developing a school's vision with teachers and providing them with personalised opportunities for intellectual stimulation. Balkar (2015) found that school organisational climates characterised by support and pressure, where pressure was thought to stimulate teachers to concentrate on their work in a more disciplined manner, positively impact the innovative behaviours of teachers. They also found that the cultural characteristic of cohesion had no effect on the innovative behaviour of teachers, which implies that climates characterised by teamwork and collaboration are not necessarily important for innovation in schools. This juxtaposition of need for support but not necessarily cohesion can be considered alongside the analysis by Thurlings et al. (2014) who found that support for innovative behaviour in schools is important, but not too much support, as "weak ties" between colleagues are more related to innovation and "strong ties" to the status quo. Russell and Schneiderheinze (2005) found that not all teachers need oppportunities for collaboration to be innovative; this raises the question about the possible link between a teacher's autonomy and their innovative behaviour.

Baharuddin et al. (2019) provide significant evidence in their literature review that employees' experiences of job autonomy, in terms of their ability to generate ideas and engage in trial and error to find more creative, efficient, and effective ways to do their work, has one of the strongest impacts on innovative work behaviour in industries outside of education. The authors propose that policymakers should consider teacher autonomy when planning for schooling that supports innovation and produces innovation skills in students. Wermke and Salokangas (2015) highlight the importance of context when considering the autonomy of teachers in different jurisdictions because the meaning of autonomy varies according to different educational traditions. Friedman's (1999) model considers the two main aspects of teacher autonomy: the pedagogical aspect that focuses on such issues as curriculum development; and student teaching, assessment, and organisational aspect that focuses on issues such as staff development and budget planning. There is very little literature relating to innovation in schools and teacher autonomy in either sense.

Preliminary findings from a study by Peterson and Thomas (2020) indicate that increased teacher autonomy in rural schools may impact teachers' opportunities and willingness to incorporate innovative STEM teaching and technologies in their classrooms. Mavrogordato (2019) found in a study of charter schools in Indianapolis in the United States that, despite the ability for each charter schools to develop its own focus and curriculum (further discussed in Section 2.3), teachers in this environment often lack the ability to deliver on the ambitious expectations for innovation set by policymakers. Crawford (2001) similarly found that the accountability measures that went along with the increased curriculum and pedagogical freedoms with the intention of educational innovation in charter schools negated the autonomy they were supposed to create. Indeed, Fidan and Oztürk (2015) found that the standardising effects of reform practices (also discussed in Section 2.3) limit decision-making and prevent participation of teachers in organisational changes; moreover, "Work related factors such as prescribed pace, methods imposed by curricula, rigidly structured work, standard operating procedures and paperwork may reduce perceived autonomy of teachers at individual level" (p. 913).

Other studies have called attention to the features of school environments that are not supportive of innovation. Banaji et al. (2010, 2013) found in their study of schools in the European Union that school climates that feature a strong ethos of control as well as a very hierarchical relationship between students and teachers, and between teaching staff and managers, are highly unlikely to develop innovative teaching or creative learning methods. In addition, frequent or punitive inspections of teachers' practices or, alternatively, a complete absence of evaluation of teachers, can be destructive to innovation and creativity. Further, very high levels of independent teacher work, verging on isolation, can lead to the likelihood of established and traditional patterns of practice. Rahmat (2020) found that school-level barriers to innovation can include a lack of supportive culture for change; conservative forces within a school; lack of support or understanding from senior management; and inadequate school-based resources, particularly if the rationale for the innovation has not been persuasively articulated.

There appears to be little research specifically linking the role of the school community and parents in shaping and maintaining school cultures that support innovation. Greany (2018) found that the ways parents perceive and value innovation impact on the success of innovation and change in schools. Gellert (2005) identified parents as a relevant factor in research on innovation and systemic reform; however, systemic reform approaches tend not to refer explicitly to parents and families as components of educational change.

2.1.7 Innovation and Technology in Schools

Innovation in schools has been more thoroughly studied in relation to the adoption and integration of technology and learning. For example, Kozma (2003) reported on the findings from the International Association for the Evaluation of Educational Achievement's (IEA) *Second Information Technology in Education Study Module 2,* which was a qualitative study of innovative pedagogical practices using information and communication technology (ICT). It involved 174 case studies of ICT-supported pedagogical innovations from 28 educational systems. However, Law (2003, 2006) has suggested that, while technology was involved in these innovative approaches in the SITES-M2 schools, the selection and deployment of technology were subservient to the changed curriculum goals and pedagogical approach in these cases. Additionally, Kozma (2003) found that despite these examples of innovative practice in ICT, "most teachers in most schools are still caught in the traditional educational paradigm and make limited use of ICT" (p. 5).

Sotiriou et al.'s (2016) study of an initiative designed to support large-scale innovation in schools across Europe reported widespread successful uptake of technology-supported innovation via an "Open Discovery Space." While their study provides some useful insights into mechanisms to "stimulate, incubate and accelerate" innovative practices, these relate exclusively to e-learning and technology-supported innovations. Venezky and Davis (2002) also found in their OECD study of ICT-supported, school-wide innovations that "ICT rarely acts as a catalyst by itself for schooling change yet can be a powerful lever for realising planned educational innovations" (p. 13). In summary, while the foci of previous innovation studies have been on technology-enhanced learning, their findings show that technology in and of itself has little impact on innovation and the changing of teaching practices.

While there is often an association between the terms innovation and STEM education in regard to the integration of STEM subjects (Corlu et al., 2014) or curriculum change, no studies have been identified that specifically address the factors that allow for the innovative implementation or teaching of K–6 STEM.

2.1.8 Disruptive Innovation

"Disruption" has been associated with "innovation" in business and academia since it was first used in this context in 1997 (Shang et al., 2020). An increasing amount of literature on the theory of disruptive innovation was being published in the popular press and in business management articles (Christensen et al., 2018). Given that "disruptive innovation as a theory of change has become popular at the reformist end of the education policy spectrum" (Ellis et al. 2019, p. 105), and the concept of disruptive innovation is increasingly being associated with school improvement (Horn & Staker, 2017; Zuckmerman et al., 2018), it is important to examine the theory as it relates to schools in the context of this study.

The theory of disruptive innovation, as popularised by Christensen (1997), refers specifically to an innovation that creates a new market, eventually disrupting an existing market and displacing established market-leading firms, products, and alliances. In other words, disruptive innovations provide different values from (and are initially inferior to) mainstream products or services in terms of performance elements that are most important to mainstream customers (Yu & Hang, 2010). Eventually these products and/or services disrupt the mainstream or the incumbent by overtaking their market share. It is important to note that disruptive innovation theory relates to the evolution of the products or services over time, with progress often following the path from the fringe to the mainstream (Christensen et al., 2015). The innovation does this by "redefining quality in a simple and often disparaged application at first and then gradually improves" (Christensen et al., 2011, p. 2), and it earns more market share over time as it develops the capability to tackle more complicated problems.

In an educational context, disruptive innovation refers to innovative teaching approaches displacing more traditional teaching methods. It is useful to consider innovation here in the light of what Christensen (2014) has called "sustaining" versus "disrupting" innovations. Sustaining innovations allow a company, or in this case a teaching practice or approach, to stay relevant or successful, yet in an improved form. An example is the use interactive whiteboards, which improve the teaching and learning experience but still reinforce the traditional teaching methods of teacher as instructor. Disruptive innovations are those that are different from existing practices, might initially cause discomfort or could be disparaged, and have the potential to eventually take over or supplant the existing practices.

Christensen et al. (2008) suggest online personalised and student-centric learning is an example of potential disruption in the school education context (noting that disruption rarely arrives as an abrupt shift and is rather a process that develops over time). They further outline a "hybrid" category to describe an innovation in a sustaining phase on the path to disruption (Christensen et al., 2013). A hybrid includes both the old and new technology and targets existing customers, rather than non-consumers, whereas a pure disruption does not offer the old technology in its full form. An example they provide is "flipped" learning in its online blended-learning sense. Flipped learning incorporates the main features of both the traditional classroom and online learning, but it is not a completely personalised, online mode.

According to Christensen et al. (2013), a common misreading of the theory of disruptive innovation is that disruptive innovations are good and sustaining innovations are bad. Sustaining innovations, they contend, are vital to a healthy and robust sector, as organisations strive to make better products or deliver better services. Disruptive innovations, in contrast, do not bring "better" products to existing customers (students) in established markets (traditional schools). Instead, they offer a new definition of what is good, which typically means simpler, more convenient, and less expensive products that appeal to new or less demanding customers. Over time, products and services improve sufficiently to intersect with the needs of more demanding customers, thereby transforming a sector.

Law (2008) argues that because the disruptive innovation theory relies on the market to determine the disruptive potential of an innovation, the theory as it stands does not translate to a school education setting, where the term "market" has less relevance. She outlines an alternative to the disruptive versus sustaining innovations dichotomy that she says better defines the relationship between an innovation (in this example technology) and pedagogical practices. She conceptualises this alternative as sustaining versus subversive innovations, depending on whether the technology strengthens existing pedagogical processes to better achieve existing curriculum goals or it brings about new goals, new processes, and new relationships in an educational context. Nevertheless, all the modes of innovation just described – sustaining, hybrid, disruptive and subversive – are innovations in the sense that they are new approaches to a specific school context that add value to classrooms and learning.

2.1.9 Innovation and STEM Education

A comprehensive outline of the STEM education literature is included in Section 2.3, including an exploration of STEM as it relates to innovation in schools. However, it is important to note here that STEM education itself can be seen as an innovation in schools (Herschbach, 2011; Holmlund et al., 2018; Nadelson et al., 2015).

2.2 STEM Education

> How do we achieve this vision? We instil creativity, innovation, and a passion for STEM from an early age, and we maintain that engagement and enthusiasm throughout their lives. Doing so will unleash an innovation culture, teaching learners of all ages to take risks, be creative, and problem-solve (National Science Foundation, 2020, p. 8)

The emergence of STEM as an acronym in the late 1990s occurred in the context of concern in the US about the inadequate state of science, technology, engineering, and mathematics education (Xie et al., 2015), particularly in light of the forecasted continuing importance of these subjects for economic prosperity. The need to strengthen mathematics and science education and thus ensure global competitiveness in the 21st century and beyond has been emphasised in several US national education reports since the early 1980s (Breiner et al, 2012). STEM has since become a growing focus in education globally, from the primary to higher educational levels. STEM education is evolving into a "meta-discipline" that, in theory, removes the traditional barriers between STEM subjects and, instead, "focuses on innovation and the applied process of designing solutions to complex contextual problems" (Kennedy & Odell, 2014, p. 246).

2.2.1 STEM Integration

A problem highlighted in the research literature around STEM education is that there are different interpretations of STEM education and STEM integration (Breiner et al, 2012; Brown et al, 2011; English, 2016, 2017). "No clear consensus exists on the nature of the content and pedagogic interplay among the STEM fields" (Holmlund et al., 2018 p. 2). Hence, definitions of STEM education vary, and there is conjecture about whether it really is a meta-discipline, given that the STEM disciplines largely remain disconnected, traditional, discipline-specific educational practices (Sanders, 2009).

Blackley and Howell (2015) have noted the continued struggle, particularly for primary schools, to "enact the STEM agenda" as "teachers have defaulted to the notion of S.T.E.M. rather than STEM" (p. 104). Supporters of integrated approaches to K–12 STEM education argue that teaching STEM in more connected ways, especially in the atmosphere of real-world issues, makes the STEM subjects more conceptually relevant and engaging, resulting in increased understanding across the disciplines (Becker & Park, 2011; English, 2016, 2017; Fitzgerald et al., 2020; Honey et al., 2014; Nadelson & Siefert, 2017; Sias et al., 2016). It has also been noted that while in the "real world" of work where the domains and disciplines of STEM are often integrated (Berry et al., 2012; Nadelson & Seifert, 2017), STEM subjects in schools are entrenched in the domains of knowledge (Herschbach, 2011). As Fitzgerald et al. (2020) point out, STEM as an integrated whole is not an acknowledged component of the prescribed curriculum in many parts of the world. Tang and Williams (2019) found in their literature review that while it is important to recognise the discipline-specific knowledge, skills, and pedagogies of the discreet S.T.E.M. subjects, several skills overlap and the notion of a "STEM literacy" as an educational construct is useful in capturing the common set of skills that need to be emphasised in the teaching and learning of the STEM areas. However, the innovative teaching of STEM in schools remains a potential systemic issue in that discipline-specific curriculum constraints may hinder the meaningful integration of STEM subjects.

There is yet to exist a universally accepted pedagogical exemplar of STEM integration. Handal et al. (2018) use the term vertical integration to categorise those practices that fit into a "silo" approach to STEM pedagogy, in that the STEM curriculum is taught separately from on-going classroom programs or compartmentalised in the form of after-school or lunch clubs, competitions, one-off STEM-based lessons, or needs to be taught by a specialist. In contrast, a horizontal integration modality refers to the implementation of STEM pedagogy as a cross-disciplinary, whole-school approach. Handal et al. suggest a number of principles of exemplary K–12 STEM pedagogy, although they concede that these are not STEM specific but "also critical building blocks for any quality learning environment" (p. 5).

Project-based learning has been named as particularly suited for STEM learning as an approach in which students can engage in interdisciplinary inquiries focused on real-world issues in ways that are relevant and similar to the actual collaboration that takes place within the STEM fields (Capraro & Jones, 2013; Slough & Milam, 2013). A growing number of researchers have noted "makerspace" or "making" as a way to support integrated STEM learning (Barton et al., 2017; Bevan et al., 2015; Blackley et al., 2017; Oliver, 2016; Vossoughi & Bevan, 2014; Weng et al., 2021), and early STEM literacy (Hachey et al. 2022; Perez et al., 2017). Makerspace can generally be described as a physical educational space with resources tools and equipment allowing students to pursue technical projects using self-directed learning, curious play and invention with the aim of learning by trial and failure (Oliver, 2016). According to Blackley et al. (2017), makerspace is the deliberate positioning of student learning in contexts that require the drawing together of STEM skills and knowledge to create, construct, and critique a product or artefact. "Tinkering" has also been recognised as a branch of making that emphasises STEM-rich creative, improvisational problem solving (Bevan et al., 2015; Bevan et al., 2014).

2.2.2 Innovation and STEM Education

As mentioned earlier in this chapter, STEM education itself can be seen as an innovation in schools. Holmlund et al. (2018) argue that "enacting STEM education entails innovation" (p. 16) and that there are various instructional models and emphases in STEM education "that are shaping reform in many educational systems" (p. 2). Herschbach (2011) contends that "STEM represents a way to think about curriculum change" (p. 98). Nadelson et al. (2015) argue that teaching integrated STEM is an educational innovation that involves novel curricular and instructional approaches. Additionally, for Nadelson and Seifert (2016), because STEM education requires innovative approaches to teaching and learning, comfort in teaching integrated STEM is representative of a teacher's general comfort with educational innovation.

Further, STEM integration has been shown to have the potential to develop the foundations of disruptive thinking, and thus foster learning innovation (English, 2018) (see Section 1.8.3). According to English (2018), developing students' skills so they can cater for an environment of increasing disruption should be a primary goal for schools; this can be done by nurturing STEM literacy in students via integrated learning in STEM, which can foster "learning innovation." Learning such skills facilitates disruptive innovation and involves the development of both discipline content knowledge and the adaptation and application of this knowledge to the solution of new problems (English & King, 2018). This aligns with the work of Sias et al. (2016), who argue that innovative practices and approaches to STEM teaching in schools should reflect innovations in society, the structures of our culture, and the knowledge and skill demands of the current age.

2.2.3 Barriers to STEM Education

Williams (2011) has called attention to several long-held systemic and structural school features that can impede the integration of, or even the interaction of, STEM subjects. These include rigid school timetables and curriculum structures, insufficient awareness by teachers of other subject areas, inflexible classroom design, and inadequate forms of assessment. Similarly, Herschbach (2011) has raised curriculum issues surrounding STEM implementation, noting that the implied integrated characteristics underlying STEM are in direct contrast to widespread patterns of curriculum organisation in schools. Nadelson and Siefert (2017) also argue that the K–12 educational system is overwhelmingly discipline based, which acts as a substantial barrier to adopting an integrated STEM curriculum, which requires a problem-based curriculum. Hunter (2020) also calls restrictive curriculums "red lights" to the integration and teaching of STEM, and Reid (2020) refers to them as "blockages" to change.

Honey et al. (2014) identify large-scale assessments as the biggest challenge to innovative approaches to STEM education and that existing assessments tend to focus on knowledge in a single discipline. They also note that assessment more broadly, from formative assessment at the classroom level to large-scale state assessment for accountability, has the potential to limit the extent to which integrated STEM can be incorporated into K–12 education. In addition, Blackley and Howell (2015) emphasise the problems associated with "engineering" not being a subject in the K–6 curricula. Wilson (2020) highlights the difficultly with STEM learning innovation, arguing that a culturally responsive STEM pedagogy that is required to engage diverse learners must rely on innovation and experimentation by educators, yet teachers are often constrained from exploring different and responsive STEM practices, particularly in disadvantaged communities. That is, there is often increasing pressure for a narrowed curriculum to address perceived deficiencies in disadvantaged student outcomes as reflected in standardised testing results. Consequently, teachers often lack the professional freedom to make decisions about the contents, forms and locations of teaching and learning activities; hence, there is the "real risk that the students who would benefit the most from innovative and holistic pedagogies might be on the receiving end of a more reductionist approach to both science and STEM learning" (Wilson, 2020, p. 24).

Lamberg and Trzynadlowski (2015) also highlight the variance in understanding and application of STEM in elementary schools as a problem. As outlined in Section 2.3.1, there are various instructional approaches emerging in the literature, without a widely acknowledged pedagogical exemplar for STEM integration. However, Holmlund et al. (2018) question the importance of achieving a single, worldwide definition of STEM education, given the variety of institutionalised practices and school contexts within which STEM education is enacted.

2.2.4 STEM Education and Teachers

A theme that often emerges in policy discussions and the research literature regarding STEM, particularly in the K–6 settings, is that of the expertise of teachers. There have been calls for improving teacher quality, and with them demands for increased accountability and for standards relating to mathematics and science education (Gonzalez & Kuenzi, 2012). Honey et al. (2014) suggest that teacher expertise in STEM content knowledge is a key factor in determining whether integrated STEM education can be done in ways that produce positive outcomes for students. Nadelson et al. (2013) argue that in elementary teachers in particular, many have constrained background knowledge, confidence, and efficacy for teaching STEM that may hamper student STEM learning. Nadelson and Seifert (2017) name teacher STEM knowledge and professional mindset as major challenges to implementing integrated STEM curriculum. They argue that teachers who do not feel they have sufficient knowledge of, or are unwilling to learn rapidly, STEM contexts and concepts are not likely to be willing or capable of supporting an integrated STEM approach to teaching and learning. Becker and Park (2011) found that the implementation of integrative STEM approaches is highly dependent on teachers' dispositions and perceptions, curriculum boundaries, and the rewards and supports offered within their specific school contexts.

In Australia and internationally there are also concerns about the lack of teachers who are qualified or equipped to teach STEM, with studies calling for further professional development for teachers in STEM capabilities (Borgerding, 2015; Fraser et al.2019; Goldhaber, 2015; Hunter, 2020; Hutchison, 2012; Xu et al., 2019; Mills et al., 2020; Timms et al. 2018; Wright et al., 2019). Lee and Nason's (2013) work has focused on recruiting "STEM-talented" and STEM literate students to teacher education, and Watters and Diezmann (2015) examined the experiences of science and mathematics graduates recruited to enhance the quality of STEM teaching. Much of the work, such as that by Borgerding (2015) who studied the recruitment of Early STEM majors into secondary science teaching careers, focuses on high school teaching. There appears to be a lack of literature investigating teacher recruitment in relation to K–6 STEM.

2.3 Innovation and School Reform

> Some schools' ability to trial and sustain their innovative practices were directly and negatively impacted by policy settings. The policy settings, on the one hand, spoke the rhetoric of innovation, risk taking and so on, whilst on the other hand, subjected these schools to things such as centralised testing procedures, which clearly belonged to the excellence side of the policy initiative. (Smith, 2006, p. 2)

Issues surrounding global education reform have been named as key barriers to successful innovation in schools (Sahlberg, 2009). When studying the implementation of innovative STEM learning, it is therefore necessary to consider macro-level features (including educational policies and legislation, and systemic factors) that can influence innovation in schools. In addition, "STEM is not simply an approach to improving science, mathematics and technology education. Rather, it is a fundamental repositioning of the goals and objectives of formal education to better support national innovation" (Lowrie et al., 2018, pp. 6-7). Given the current global economic focus on innovation, a theme emerging in the literature is that change and reform exist in an educational policy environment of standardisation and restriction.

2.3.1 "Marketisation" of Schools

According to Sahlberg (2006), the education reforms that many countries have instituted in recent years to provide their citizens with knowledge and skills for a dynamic knowledge-based economy have been increasingly embedded with "market values like productivity, effectiveness, accountability and competitiveness" (p. 262). The assumption has been that education will improve and transform according to the logic of enhancing performance of market economies. Hence, many governments have introduced market mechanisms into their education systems with the aim of improving the quality of education and of promoting innovation in education "within classrooms, in governance and management, in content, in information and delivery systems" (Lubienski, 2009, p. 12).

Further, there is a body of literature that discusses the shift in the purpose of education from democratic service to economic control. According to Codd (2005), education in Western nations has historically been aimed at the maintenance of social democracy through building literate and informed citizens, but it has taken on a neo-liberal purpose, placing it increasingly within the orbit of economic policy. In this view, government spending on education is an investment in human capital, and education itself is causally related to economic growth. Thus, the primary goal of education policy has become "to enable individual learners to acquire the skills and abilities required for them to perform more effectively, hence more productively, within a changing global labour market" (p. 194). In this context, it may be argued that schools are increasingly operating in accordance with the principles of corporate managerialism, or in other words, according on a model imported from the world of business (Hill, 2007).

It might be assumed that innovation would thrive in the environment of "marketisation" (Apple, 2001; Sahlberg, 2006; Waslander et al., 2010) emerging in education systems, which has been aimed at "opening doors to competition and choice" as a means of improvement (Sahlberg, 2006, p. 262). However, "despite calls for opening education to the marketplace, there is limited evidence that competition and choice spur innovation" (Preston et al., 2012, p. 1). As Gorur (2013) argues, market features have been applied in education systems in countries like the US, the UK, and Australia, not in the fashion of a "free market" but more in the style of a "quasi market." This is typically characterised by increasing devolution of responsibility to schools, particularly in the recruitment of teachers and the management of the budget; complexity around which schools children can attend; greater competition and accountability to enhance school performance; and consequences for "failing schools," including funding sanctions, amalgamations, "takeovers", and closures (p. 217).

2.3.2 Standardisation in Schools

Most notable in the context of this study is the paradoxical consequence of the *marketisation* of school systems, which has led to the increased use of *standardisation* and *accountability* as means of improvement and growth across school systems (Sahlberg, 2006). That is, what has emerged over recent decades is "an education system in many countries that in some respects enables and encourages autonomy at a school level in the name of competition and parental choice, but that simultaneously emphasises strict accountability" (Knight, 2020 p. 205).

This standardisation has come about because of global responses to educational improvement and of environments in which knowledge and therefore education have become international commodities (Lundgren, 2011). In this era, large-scale comparative assessments such as the OECD's Programme for International Student Assessment (PISA), which were designed to evaluate mathematics, science, and literacy skills as a 'performance indicator' or measure of economic potential of a nation (Popkewitz, 2011), have emerged as major determinants of education policy and systemic control of teaching and learning (Harris & Jones, 2018). PISA results have created the phenomenon of the 'high performing system,' where nations look to emulate the features of education systems that perform well in PISA tests (Breakspear, 2012). In fact, "policies implemented in response to PISA have demonstrated remarkable alignment within economic and political subgroups" (Wiseman, 2013 p. 303). Critics have noted the irony that by aiming to produce the innovators of tomorrow by seeking to ensure adequate skills in mathematics and science in their future workforces, governments seek to emulate peer education systems rather than innovate. That is, reforms have been designed by applying solutions designed in other countries and by imitating education policy principles found in books and journals (Sahlberg, 2016). As Harris and Jones (2018) outline, discussions about the educational methods used in high-performing nations tend to erase any serious consideration of culture and context in favour of locating the best and most transferable solutions.

This phenomenon has been termed the global education reform movement (GERM) (Sahlberg, 2016), which Reid (2020) says is the "the educational child of neoliberalism" (p. 15). As governments and educations systems have sought to reform by implementing what works in high performing systems, this has led to introduction of education standards, indicators, and benchmarks for teaching and learning, aligned assessments and testing, and prescribed curricula (Sahlberg, 2006). As a result, various forms of accountability have emerged whereby school performance and raising the quality of education are closely tied to the process of accreditation, promotion, and financing. Biesta (2017) argues that this has created a climate of statistics and measurement in which concern seems to be placed less with what makes education good, and more with what makes it effective or efficient. Au (2011) describes this as the emergence of a "new Taylorism", where reforms have arguably de-professionalised teachers and replaced teacher agency with prescriptive curricula and increasingly oppressive regimes of testing and evaluation (Priestley et al., 2013).

Despite decentralisation of responsibility for some aspects of school administration, management practices prioritising uniformity over inventiveness prevail. According to Rose (2016), in some ways schools might be thought of as "factories of education" in which the "brains" (administrators) at the top direct the "hands" (teachers) lower down. In this environment of "the disappearance of teaching and the teacher" (Biesta, 2013, p. 35), there appears little value for the teacher as innovator, and indeed, most teachers report that any innovation they make will not be valued or recognised (OECD, 2012). As Hargreaves (2016) argues, school autonomy in practice tends to concern managerial issues such as staffing and budgets rather than curriculum and pedagogy. The type of reform that appears to encourage choice and innovation but ultimately leads to standardisation and restriction has played out similarly in the large public education systems of Western countries. It is important, therefore, to explore the impact of neoliberal thinking on innovation in schools, and to capture an understanding of how the contextual factors impacting different school systems can influence school innovation and STEM learning innovation.

2.3.3 Global School Reform

Giles and Hargreaves (2006) found that government-sponsored reform and changing power relations between states and local school districts have tended to weaken the sustainability of innovative initiatives in schools over time, and there is a tendency for large-scale standardised reform movements to displace locally initiated innovation and reassert the traditional grammars of schooling, leaving innovative schools imperilled . Although GERM has grown to reach many countries across Europe and in the OECD (Verger et al., 2019), it has its origin in countries such as the UK, the US, and Australia (Sahlberg, 2016). Most of the literature highlighting these reforms and their potential to impact innovation in schools therefore features the experiences of these countries. The following review discusses reforms in England, the US, Australia, and Europe to show how the issues inherent in such reforms work against innovation in schools.

2.3.3.1 School Reform in England. School reform in England (rather than the UK, given the different developments in schooling in Scotland, Wales, and Northern Ireland) began with the 1988 Education Reform Act, which witnessed the first national curriculum in England and the introduction of standardised testing for all students in all schools (Lingard & Lewis, 2015). School reforms in England have been described as a "self-improving school-led" system (Greany & Waterhouse, 2016, p. 10), which can be characterised in terms of policy freedoms (autonomy) and structural constraints (accountability). The policy freedoms are embedded in reforms to school organisation and governance, including the legal right of academies and free schools (state-funded, non-fee-paying schools in England, independent of local authorities) to deviate from the National Curriculum. Introduced as part of New Labour's "Higher Standards, Better Schools for All" (DfES, 2005), this academies policy was intended to allow designated under-performing schools (measured against government-imposed targets) to "opt out" of the governance of local authorities and to self-govern or enter into partnerships with outside sponsors (such as philanthropic entrepreneurs) (Wilkins, 2012). This was extended by the Conservative government in 2010, making it possible for all schools to convert to academy status. The structural constraints outlined by Greany and Waterhouse (2016) focus on a pervasive accountability regime, including mandatory national tests, regulated exams and a high stakes school inspection system, all of which the authors found impose a level of standardisation and limit the potential for innovation.

2.3.3.2. School Reform in the US. The reform and regulatory climate in the US has been described as the "age of accountability" (Nordgren, 2015), wherein policymakers and funding agencies use "carrots and sticks" to increase student achievement, leaving an environment of standardisation that limits the ability of teachers to find innovative ways to "help their students find economic success in their futures" (p. 2). That is, Nordgren reasons, school success in the US continues to be assessed using quantifiable data that is easy to report to the community and in the media, rather than arguably what really needs to be known for school graduates to succeed in the global economy and contribute to a public democracy. Kretchmar et al. (2013) argue that the shift towards neoliberal thinking in the US has had an especially profound impact on education, with several policies enacted under the belief that schools are failing due to limited options, management failures, lack of accountability, bureaucracy, and uncooperative teacher unions. Because these things are seen to threaten economic stability and international standing, "policies that promote deregulation, accountability, and systems of choice [are] the inevitable solution" (p. 744).

No Child Left Behind Act. The main neoliberal reform initiative referred to the literature of the past two decades is President George W. Bush's federal legislation the No Child Left Behind Act (NCLB) of 2001/2002, which amended the Elementary and Secondary Education Act of 1965, and followed change initiatives stemming from a 1983 Regan government report *A Nation at Risk* (Gardner et al., 1983), which outlined

> [the nation's] once unchallenged pre-eminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world … [and] the educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a Nation and a people. (p. 5)

NLCB substantially increased testing requirements and set demanding accountability standards for school districts and states, including measurable yearly progress measures for all students and for subgroups of students defined by socioeconomic background, ethnicity, and English language proficiency (Linn et al., 2002). Schoen and Fusarelli

(2008) studied the impact of the NCLB on the behaviours of teachers and school leaders, specifically the centralising, standardising tendencies of the legislation in juxtaposition to the types of teaching and leadership required to lead 21st-century schools. They argued that the isomorphic behavioural responses to the NCLB were conflict with the pedagogical and leadership behaviours of the 21st-century schools movement:

> The pressing need to be innovative and to prepare students with 21st-century skills while complying with and meeting the many mandates of NCLB creates tension among school leaders and teachers who feel as though they are being pulled in opposite directions. Many conscientious school leaders are trying to be simultaneously responsive to calls for innovation, critical thinking skills, adaptability, and creativity (21st-century skills) yet still meet the demands and adequate yearly progress (AYP) testing targets of NCLB. The ever-present threat of failing to make AYP, with its public embarrassment, stigma, and outcomes-or-else philosophy, produces fear and conformity among educators—both of which stand in stark contrast to the objectives of 21st-century schools. (p. 182).

Despite this type of criticism, the test-based accountability approach was strengthened under the Obama Presidency in 2009 through the Race to the Top (RTTT) initiative in which grants were awarded to states who agreed to enact certain educational policies. According to McGuinn (2012),

> RTTT is fundamentally about two things: creating political cover for state education reformers to innovate and helping states construct the administrative capacity to implement these innovations effectively … [and] RTTT supports only those states that have strong track records and plans for innovation and can demonstrate key stakeholder commitment to reform. (p. 137).

These "commitments to reform" included instituting performance-based evaluations for teachers and principals based on multiple measures of educator "effectiveness" and the agreement by most states to a common core for curriculum, which saw even further growth in policy and funding based on test results (Lingard & Lewis, 2015).

However, rather than generate widespread innovation, the accountability and standardisation that expanded under RTTT resulted in the narrowing of curricula and pedagogy (Berliner, 2011) because teachers felt forced to "teach to the test" to achieve the expected measurable results (Lingard & Lewis, 2015). Importantly, research continued to find that teachers perceived this climate of compliance and conformity at the expense of teacher autonomy and self-direction to negatively affect their abilities to foster creativity and creative thinking in the classroom (Olivant, 2015). Questions also arose about the lack of teacher capacity for "rich, creative pedagogy" and the growing scarcity of "independent-minded, intellectual, risk-taking, creative teachers" when teachers are recruited and trained under the regime of standardisation (Bloom & VanSlyke-Briggs, 2019, p. 107).

Charter Schools. One neoliberal reform that has often been associated with innovation in US schools is the Charter School movement, which began in the early 1990s and was greatly expanded under the RTTT initiative (Mora & Christianakis, 2011). Charter schools are publicly funded schools (sometimes also supported by private funding) that are created and operated by organisations other than local school districts. The theory behind the innovative potential of charter schools is that they are exempt from certain state and district rules and regulations and in instead are held accountable to standards stipulated in their charters, which provides the space for new educational models and services to emerge and develop. Indeed, many charter school organisations claim innovation as the main reason to establish a charter school (Andrews & Rothman, 2002; Lubienski, 2004; Renzulli et al., 2015). However, the achievement of innovation in these schools has been questioned, and according to Lubienski (2004) "a comprehensive review of practices in charter schools indicates that, although some organisational innovations are evident, classroom strategies tend toward the familiar" (p. 395). Other studies have found that despite the innovation potential mentioned, charter schools in practice are not more innovative than traditional public schools (Preston at al., 2012).

Teach for America. Teach for America (TFA) is an initiative that since 1990 has placed recently qualified, non-education college graduates, who are trained in 5-week summer institutes, in classrooms in low-income communities with a commitment to teach for 2 years. The aim of the initiative is to recruit high-performing graduates, "the best and the brightest", to fill teaching shortages in urban and rural districts, as well as to develop future educational leaders to close the growing "achievement gap" (Teach for America, 2018). The thinking is that by employing teachers who embody leadership qualities, such as “grit”, bold risk taking, and a strict focus on measuring results, school administrations will introduce broader skills and a level of entrepreneurship into the educational sphere to assist in redressing educational inequality (Cuban, 2013; Trujillo et al., 2017).

Most of the research on TFA has focused on the classroom effectiveness of the teacher recruits and how long they remain in classrooms, with very little research on the question of whether these recruits achieve their mission declared by the TFA as change agents and future leaders in eliminating educational inequality (Higgins et al., 2011). Similarly, there appears to be a lack of literature on the impact of otherwise trained or career change teachers on innovation in schools, either inside or outside of the US. Australian researchers Varadharajan and Schuck (2017) established that career changers seem well able to prepare students with a range of skills for life beyond school and for work in an increasingly globalised world.

2.3.3.3. School Reform in Australia. In the Australian context, over the past two decades the federal government has played a more prominent role in working with the states and territories to set policy directions for school education (Masters, 2020). Reforms are increasingly being driven by market-based logic, and “Australian governments borrow heavily from neoliberal reforms in the United Kingdom and the United States, despite a vast body of research that has highlighted the negative effects of many of these reforms on schools, educators and students” (Savage, 2017, p. 150). Among the national objectives that have emerged during this time are improving overall levels of student performance, reforming school funding arrangements, and enhancing the effectiveness of teaching and school leadership. To deliver these reforms, national agencies were established, which led to the creation of an Australian Curriculum implemented in all states and territories, a National Assessment Program in Literacy and Numeracy (NAPLAN) to assess, report and monitor student performance, accompanied by a national website to publicly report school performance (Martin & Macpherson, 2015), and national professional standards for teaching (Masters, 2020).

Professional teaching standards define accomplished or high-quality teaching, and “are one of the main tools through which policy makers and education authorities, in many countries, including Australia, hope to make teaching practice less variable, more reliable and increasingly effective” (Mulcahy, 2011, pp. 94-95). Despite widespread acceptance that the professional standards acknowledge that teacher quality is essential for student achievement (Gannon, 2012; Mulcahy, 2011), some scholars have argued that professional standards symbolise a distrust of the professional judgement of teachers. According to Thomas (2011), the policy discourse surrounding the introduction of professional teaching standards in Australia has "depicted teachers in a deficit way, but advocated using professional standards in different ways to address this deficit" (p. 4). For Gannon (2012), the standards are part of "the creeping of neoliberal managerialism into education and an audit culture that emphasises performance measures of students, teachers, schools and systems" (p. 73), and they ignore earlier discourses of teacher professionalism that "value teacher autonomy, expertise, altruism and collegiality" (p. 74). In other words, along with less professional trust comes arguably less professional freedom for teachers to be innovative.

Moyle (2010) argues that these policies work against innovation in schools for both students and teachers because the environments in which innovation and creativity can flourish are those in which there is trust and where the consequences for students and teachers of making mistakes are reduced:

> An irony of Australia's education policies is that they place an emphasis on achievement, yet the fostering of creativity and innovation is stifled where there is a fear of failure. This fear reduces the capacity of both students and teachers to take risks, and therefore impedes their abilities and opportunities to be creative and innovative. (p. 12)

2.3.3.4. School Reform in Europe. School policies in many European countries have distanced themselves from the idea that market-based ideologies can reform education systems (Sahlberg, 2016). Finland, which has education policies diametrically opposed marketisation and privatisation, has famously continued a "relaxed and unorthodox approach to schooling" (p. 131), yet it outperformed the other countries in the OECD in the first three PISA surveys. In contrast, Ireland is an example of a European country which had a historical resistance to the dominant global education reform movement but has to some extent overturned this position in response to poor results in PISA testing (Conway, 2013). Despite a more restrained approach to neoliberal marketisation in schools than in England and the US, in Irish education policy the "scope, intensity and intent of accountability have increased significantly in recent years" (Conway & Murphy 2013 p. 16), with accountability determined by such things as system quality through a core curriculum, an audit culture, and standardised testing (albeit of somewhat lower stakes).

2.3.4 Schools as Institutions

Aside from issues of reform, the institutional nature of schools can impede innovation. In line with teaching as it was organised a century ago, students continue to be grouped by age, learning predominantly happens in a classroom, knowledge is divided into distinct subjects, and student "achievement" is measured by examination. Despite decades of education reform, the basic features of public education remain largely untouched, the institutional environments in which schools operate remain static, and achieving change is messy and slow (Darling-Hammond, 2015; Fadel et al., 2015; Resnick et al., 2010; Williamson & Payton, 2009). According to Benavides et al., 2008, "The main modus operandi of school administration and instruction are resistant to change" (p. 28). In other words, as Craft (2005) points out, schools lack the flexible and risk-taking characteristics of innovative organisations.

2.4 Conclusion

This chapter has provided an overview of the literature that underpins this study. It outlines the history and economic background of the concept of innovation and its extension into social spheres (social innovation) and learning. It discusses the emergence of integrated STEM learning as a metadiscipline and notes the gaps in the literature on innovation and STEM, particularly in K–6 education. A comprehensive analysis of the meso- and macro-level features that can influence innovation in schools has been provided, highlighting the key issues in education reform to be considered when examining STEM learning innovation.

Despite the prominence of innovation in modern discourse, there is limited research literature that addresses issues of innovation that apply specifically to school education and that relate to a broader understanding of teaching and school leadership. Instead, much of the work in innovation and innovative pedagogy comes from higher education, or it focuses on technology-enhanced learning or specific teaching practices such as active learning, constructivist teaching, and self-directed learning. In addition, some of the studies reviewed here are more than a decade old, and it is necessary to determine if their findings apply in the current social, economic, and political contexts. Hence, further research is needed to support a deeper and contemporary understanding of innovation in schools, including both teaching and school leadership.

Much of the literature that does exist on innovation in schools reflects the global reform orthodoxy in education policy that refers to innovation in terms of *improvement* and *effectiveness* as measured by student performance in standardised tests. This is despite the anti-innovation paradox of standardisation that various scholars have noted as resulting from these reforms. It is important, therefore, to explore the impact of this type of thinking on innovation in schools, and to capture an understanding of how contextual factors impacting different school systems can influence innovation. Additionally, research on innovation and STEM education is expanding, and it will be useful to extend this to both teaching and school leadership, particularly in K–6 settings.

This chapter has established the need for a better understanding of innovation in the school context and of the institutional, regulatory, and other influences that can enhance or inhibit innovation in K–6 STEM learning. Chapter 3 details the methodological justification and research processes of the study, outlining the pragmatic sociocultural approach used in the research design.

Chapter 3

Methodology

Chapter 2 reviewed the literature relevant to this study, including innovations systems theory; as well as innovation in an educational context; disruptive innovation theory; STEM in the context of innovative teaching and primary education; and innovation as it relates to school reform and education policy. This chapter outlines the methodology used in this study. It describes the pragmatic sociocultural perspective informing the research design, with narrative inquiry as the overarching approach, and the Delphi method used in the initial phase to extrapolate a comprehensive understanding of innovation in schools.

The purpose of this study is to contribute to a deeper and contemporary understanding of innovation in schools, in regard to both teaching and school leadership for innovation, including an exploration of how the contextual factors impacting different school systems can influence innovation. The study also aims to reveal the institutional, regulatory, and other influences that can enhance or prevent innovation in K–6 STEM learning There are three research questions:

1. How is school innovation defined by experts in the field?
2. What are the factors that foster and limit innovation in schools?
3. What factors enhance or prevent innovation in K–6 STEM learning?

Importantly, the first two questions needed to be answered in order to address the third question. That is, a nuanced understanding of innovation in a school context needed to be developed before the factors that enhance or constrain innovative teaching of STEM could be examined. Therefore, the investigation of the first two questions (which guided the first phase of the research) directly informed the investigation of third question (which guided the second phase of the research).

3.1 Theoretical Foundations

According to Mackenzie and Knipe (2006), a researcher should identify their philosophical intent, or paradigm, to establish from the outset the motivation and expectations for the research. Without first nominating a paradigm, there is “no basis for subsequent choices regarding methodology, methods, literature or research design” (p.

194). Fundamental to a research project is the researcher's genuine passion and desire to uncover answers to the research problem as a response to what pragmatist John Dewey (1978) outlined as the basis to inquiry, a "felt difficulty." That is, in Dewey's philosophical version of pragmatism, inquiry begins with an emotionally felt difficulty, an uncertain situation, and this conflict is resolved by thinking and acting in a creative and future-oriented manner (Elkjaer, 2009). Pragmatism is purpose driven and based on the principle of utilitarianism (Schoen, 2011), allowing the researcher to study areas that are of interest to the field, while embracing methods that are the most appropriate, rather than in strict theoretical alignment to a research approach (Creswell, 2003; Tashakkori & Teddlie, 1998). As such, the epistemological stance of this current research is pragmatism.

This pragmatist standpoint is typically characterised by "a positive attitude toward integrating practice, by rejecting traditional dualisms, by preferring empirical over idealistic or rationalistic approaches, as well as agreement that knowledge and thinking be seen as forms of activity—as experimental inquiry" (Frega, 2011, p. 1). The pragmatic paradigm places the research problem as central and allows for the application of multiple approaches to understanding the problem (Creswell, 2003). With the research questions "central", data collection and analysis methods are chosen as those most likely to provide insights into the questions without strict philosophical loyalty to any alternative paradigm (Mackenzie & Knipe, 2006).

As Glăveanu (2021) argues, a pragmatic view of knowledge is particularly suited to the study of innovation and creativity, including in rethinking education. That is, to be a pragmatic educational researcher is to hold the view that by seeking to understand how differences in perspectives reinforce or clash with each other, they can seek new possibilities and understandings. For Glăveanu, the pragmatic tradition also aligns well with sociocultural theory, and "what enables the possible is difference" (p. 2), particularly the difference between perspectives, and that the notion of perspective "captures the relation between person and world (the latter including the self, other people, and the social, symbolic, and material arrangements that make up culture)" (p. 218).

It is therefore apt to recognise that in establishing a theoretical lens for this study, its topic is situated within a space and time of significant social and cultural change. As outlined in Chapters 1 and 2, scholars and researchers, along with political leaders, policy makers, and organisations, have referred to the rapidly changing nature of society during the knowledge and information eras, the "innovation era" (OECD; 2015a; Voelpel et al., 2006; Sawyer, 2006) or the "age of innovation" (Araya & Peters, 2010; Corlu et al., 2014, Goldberg, 2018; Janszen, 2000; Krinsky, 2012; Vineyard et al., 2012; von Schomberg & Blok, 2018) and indeed in the current COVID or post COVID era (Frei-Landau et al., 2022; Makamure, C., & Tsakeni, 2022; Ngugi & Goosen, 2021; Sunita, 2020; Tsakeni, 2022). Teachers have been named as key actors in ensuring a prosperous future, and they, along with schools and school systems, have been charged with adapting to accommodate this societal transformation. Innovation is often named as the solution.

From a sociocultural perspective, innovation – like education – is culturally moderated (Beck, 2017; Moolenaar et al. 2010; Paavola et al, 2004; Rossberger & Krause, 2013). Further, in gaining an understanding of STEM education it is important to recognise that innovation is influenced by the many social forces that shape educational outcomes in society (Xie et al., 2015). That is, in attempting to unpack the elements affecting cultural change within schools, as necessitated by wider cultural change, namely, the drive for innovation and the need for STEM skills, it is fitting to apply research methods grounded in sociocultural theory (Somekh, 2007). Sociocultural theories describe learning and development as embedded within social events and occurring as a learner interacts with other people, objects, and events in the collaborative environment (Vygotsky, 1978).

These theories suggest that learning is a process of appropriating "tools for thinking", which are made available by social agents who act as guides in an individual's cultural apprenticeship (Rogoff 1990, in Renshaw, 1992). It is not just that learning occurs from others in social contexts and during social exchanges, but that the actual means of social interaction (including language) are appropriated by the individual to form the tools for thinking, problem-solving, and remembering (Wertsch, 1985). As Dewey (1916) put it, social interaction is communication and all communication is educative: "To be a recipient of a communication is to have an enlarged and changed experience. One shares in what another has thought and felt and in so far, meagerly or amply, has his [sic] own attitude modified" (p. 6). Drawing on Dewey, I seek to understand teaching and learning as they operate within a process of acquiring and contributing attributes that are valuable to the culture(s).

Scholars have argued that the pragmatic paradigm is particularly suited for sociocultural research (Schoen, 2011; Garrison, 1998). Mutually purpose driven in nature, "both sociocultural tradition and pragmatic goals emphasise research to inform practice" (Schoen, 2011, p. 26), making sociocultural research within a pragmatic framework well suited to addressing educational research questions. In addition, in alignment with a pragmatic design that avoids favouring any research methodology, "sociocultural research often builds on this idea by using data sources and types to 'zero in' and see the details and then 'zoom out' and see the big picture" (p. 25), allowing the sociocultural researcher to synthesise information and construct an understanding of individuals as they function in their natural settings.

3.2 Overview of the Research Design

> The use of storytelling as a research tool to enhance our understanding of knowledge creation and acquisition, and its conversion into innovation... is the methodological underpinning of the narrative approach (Formica, 2013 p. xi).
>
> The subject-matter of stories is human action. Stories are concerned with human attempts to progress to a solution, clarification, or unraveling of an incomplete situation. (Polkinghorne, 1995, p. 7)

The overarching research approach applied in the study is that of narrative inquiry, which recognises the innate inclination in human beings to use storytelling to solve problems and to relate to the world and its phenomena (Haven, 2007; Webster & Mertova; 2007). The word *approach* is used here because narrative inquiry is both a "phenomenon and method" (Connelly & Clandinin, 1990), and indeed "there is now a well established view of narrative inquiry as its own methodology" (Clandinin, 2016, p. 12). Although phase two of the research explicitly used narrative inquiry, the entire study was informed by narrative inquiry, wherein narrative thinking was used as a frame of reference and a way of reflecting during the entire research process (Moen, 2006). In addition, phase one of the study used the Delphi method to unpack understandings of innovation in schools to inform the wider research aims.

Previous studies have used findings from Delphi studies to inform wider qualitative research (Hasson & Keeney, 2011), including narrative inquiry in combination with the Delphi method (Engels & Kennedy, 2007; Kennedy, 2004; Isobel, 2011). Kennedy (2004) found that the narrative research can expand and enhance Delphi research findings, and Isobel et al. (2011) have argued that the combination of Delphi study and narrative inquiry provides additional insight into the complexity and subtleness of the phenomena under study. The findings from the Delphi component of this study allowed for the application of a contemporary consensus understanding of innovation when unpacking the narratives from phase two, and thus it was integral to the narrative process.

3.2.1 Phase One Delphi Study – "Setting the Scene"

During the initial phase of the research, it was important to scope the research problem among the wider education community to develop a comprehensive and contemporary understanding of innovation in schools. This was achieved via a Delphi study. In relation to the narrative inquiry in phase two, this first phase operated as "setting the scene" to establish the criteria upon which research about innovative teaching and leadership in STEM could be analysed.

Linstone and Turoff (1975) were the first to define the Delphi technique as "a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" (p. 3). This study recognises that knowledge is socially defined, and that learning can be characterised as participation in the use and transformation of socially defined knowledge (Hickey & Zuiker, 2003). The collective building of consensus regarding a shared social problem situates the Delphi technique so appropriately in the wider context of this study.

The Delphi technique is an iterative approach designed to collect and distil the anonymous judgments of experts using a series of data collections and analyses interspersed with feedback (Skulmoski et al., 2007). It allows the facilitation of an efficient group dynamic process in the form of an anonymous, written, multi-stage (or "round") survey, where feedback of group opinion is provided after each round (Heiko, 2012). This collection of expert judgements allows the development of a model or framework for addressing a real-world problem (Linstone & Turoff, 1975; Okoli & Pawlowski, 2004).

In this study, the Delphi technique solicited from expert stakeholders in the field a "convergence of opinion" (Hsu & Sandford, 2007, p. 1) on what constitutes innovative teaching and innovation in schools. Specifically, it addressed the research questions, *How is school innovation defined by experts in the field?* and *What are the factors that foster and limit innovation in schools?* The findings were used to develop a definition of innovation in schools and framework for understanding it, which then informed phase two of the research investigating K–6 STEM learning innovation.

Pragmatism is evident in the Delphi approach, given its flexible nature and that it often applies both quantitative and qualitative elements (Brady, 2015). In this study, it first involved a questionnaire combining structured and open-ended questions. The resulting quantitative information was subsequently distributed to participants in the form of a statistical representation of the group response. This "feedback process" encouraged the Delphi participants to reassess their initial judgments about the information provided in the previous iteration, allowing for consensus-building among the participants (Hsu & Sandford, 2007). The open-ended responses allowed for the construction of further quantitative items for the subsequent round. Through consulting with field experts to actively negotiate an agreed view, the Delphi facilitated a socially constructed consensus within the cultural context school education.

3.2.2 Phase Two Narrative Inquiry

Phase two involved investigating three specific examples of K–6 STEM learning innovation. Informed by and building on the research from phase one, this phase allowed the analysis and reporting on answers to the question; What factors enhance or prevent innovation in K–6 STEM learning?

Dewey's pragmatist theory of experience is often cited as the philosophical underpinning of narrative inquiry (Clandinin & Caine, 2013: Clandinin & Rosiek, 2007), and because, as Clandinin (2016) contends, narrative inquiry involves the study of human lives, which honours the lived experience as a source of important knowledge and understanding, "narrative inquiry is an approach to research that enacts many, if not all, of the principles of a Deweyan theory of inquiry" (p. 18).

Various scholars have also placed narrative research within the framework of sociocultural theory (Adama et al., 2016; Cavendish, 2011; Fante, 2022; Golombek & Johnson, 2004; Moen, 2006; Yu & Zhoa, 2021). Applying a sociocultural perspective means viewing teaching and learning as human activities conducted within institutional and cultural frameworks (Lemke, 2001). In this study, I drew on the ideas of sociocultural scholars Vygotsky (1978; 1987) and Halliday (1978; 1993), who make the explicit link between language, culture, and learning. In this tradition, Halliday (1993) argues that "language is an essential condition of knowing, the process by which experience becomes knowledge" (p. 94). Narrative inquiry is thus a suitable methodology because it is a "discourse form" in which events and happenings are configured into meaning (Polkinghorne, 1995, p. 5) and "one of the main ways in which we use language is to construct narratives or stories" (Glaveanu, 2021, p. 81). Further, Vygotsky, as well as Bakhtin (1986), established that language should be viewed in terms of its inextricable link to relations of power and change in society (Marchenkova, 2005). Moen (2006) interpreted their work to establish that narrative inquiry enables the study of teachers and their teaching in movement, "in a process of development, and within the teachers' social, cultural, and institutional settings" (p. 59).

A narrative has its genesis in traditional oral storytelling, which is essentially a form of shared cultural meaning-making (Hendry, 2009). By their nature, narrative accounts, are simultaneously individual, social, and relational constructs, and "cannot be separated from the sociocultural and sociohistorical contexts from which they emerged" (Johnson & Golombek, 2002). Cultural knowledge-making through stories and innovation are inextricably linked (Hartley & Potts, 2014; Hartley, 2020); hence, narrative research is relevant to the social climate of this study. In addition, narratives are in essence formed around a problem-solving structure (Labov 1972, 1997, 2007; Labov & Fanshel, 1977; Labov & Waletzky, 1967). This is fitting because innovation has also been named as fundamentally a problem-solving process (Beckenbach & Daskalakis, 2013; Satell, 2017; Von Hippel, 1994), and stories are used to foster, facilitate, and analyse innovation in organisations (Martens, 2014). Further, Beckman and Barry (2007) found in their research that the innovation process is one of storytelling and retelling in addition to a learning process (see Section 2.1.1). They frame the innovation process using the classic myth or fairytale structure of finding and selecting solutions to problems.

Aside from this, humans are essentially exposed to information in story format from birth and consequently have an innate ability to analyse, learn from, and remember information and experiences as stories (Haven, 2007). That is, the universal familiarity with the story structure from a young age suggests that stories are the human way of understanding and solving problems. As Hanne and Kaal (2019) put it, “It is primarily through narrative ‘telling’ that we come to ‘know’ the world” (p. 5).

This thesis relates in narrative form the important story of innovation in K–6 STEM education. In doing so, it recognises the temporal, perspectival nature of reality, creating a story of K–6 STEM that integrates different experiences. As Glaveanu (2021) argues, “Narratives help us make sense of the world and give it a more complex significance, beyond what single words or signs could ever achieve. They reflect and often integrate different perspectives, just as they articulate various positions” (p. 81). The narrative inquiry methodology allowed for the reconstruction of the experiences of the research participants in relationship to each other and to the social climate (Connelly & Clandinin, 2000). This was made possible using Connelly and Clandinin’s (2006) conceptual framework of narrative inquiry, which holds that the data should be interpreted in terms of temporality (in this case in process or transition, change in society and education), place (within the boundaries of the classroom, school, school system and education system), and sociality (social conditions within the school, school system and wider influences of cultural change).

3.3 The Delphi Study

As outlined earlier, phase one of the research used a Delphi approach to scope the research problem among the wider education community, specifically to determine a consensus view on a definition of and criteria for what constitutes innovative teaching and innovation in a school context. A modified Delphi was used for this process. While the modified Delphi technique is similar to the conventional Delphi in terms of procedure (a series of anonymous rounds with selected experts) and intent (arrive at consensus), the major modification in this case consisted of beginning the process with a set of carefully selected items drawn from a synthesised review of the literature (Custer et al., 1999), rather than using wholly open-ended questions from the outset. The main advantages of this modification to the Delphi are that it improves the initial round's response rate and, importantly, it "provides a solid grounding in previously developed work" (p. 2).

3.3.1 Panel Selection

The Delphi method is not concerned with having a generalisable sample but rather a purposive sample of individuals with specific expertise on a topic (Brady, 2015; Okoli & Pawlowski, 2004; Gordon, 1992). From their review of the literature on the Delphi process, Hsu and Sandford (2007) suggest that selecting appropriate participants for a Delphi study is the "most important step in the entire process because it directly relates to the quality of the results generated" (p. 3). These participants, or panel members, should be key experts in a field (Patton, 1990). Participant invitation criteria include "measurable characteristics that each participant group would acknowledge as those defining expertise, while still attempting to recruit a broad range of individual perspectives within those criteria" (Avella, 2016, p. 307). For this study, experts were defined as individuals with extensive knowledge of the phenomenon of innovation in school education based on their research, intense or prolonged experience, or work in educational design or leadership. The expert panel included:

- education system leaders and policy advisors,
- education and/or innovation research personnel (academics), and
- school leaders and/or leaders of innovation in schools.

For a Delphi panel to be effective, its members need to have diverse views in addition to knowledge about the many complex issues surrounding the topic of study (Pare et al., 2013; Turoff, 1970). As such, and as it was an online study, the panel was assembled "without concern for geography" (Turoff, 1970, p. 306), with the intention of including English-language speakers with appropriate international expertise. Therefore, participants meeting the above criteria were invited from Australia, the US and UK/Europe. School leaders invited to participate included those from both primary and secondary settings.

Panel sizes recommended in the literature can vary greatly from five individuals to hundreds (Delbecq, 1975; Linstone & Turoff, 1975) and "the criterion for deciding on sample size for constructing a panel of experts is not a statistical one" (Wilhelm, 2001). However, according to Ziglio (1996) and Linstone and Turoff (1975), good results can be obtained even with small panels of 1 to 15 individuals. Linstone (1978) later suggested that a suitable minimum panel size is seven. For this study, I identified 30 possible panelists from Australia, the US and UK/Europe via a literature review and a search of "professional learning networks" on Twitter and LinkedIn, with the aim of securing 10 to 15 participants.

3.3.2 Data Collection

Potential panelists were sent an email invitation to participate and a link to the survey. The initial email, sent via Survey Monkey, contained a covering letter with links to the details of the study (Appendix A) and to the participant information sheet and the information about informed consent (Appendix B). Potential participants were made aware that by clicking through to complete the survey, they would be consenting to their participation. Of the 30 possible panelists invited, 25 agreed to take part in the study. They included six education system leaders and policy advisors, eight education and/or innovation research personnel (some of whom were former school leaders), and 11 school leaders and/or leaders of innovation in schools (Table 3.1). Fourteen panelists were from Australia, five from the US, and six from Europe. The Australian respondents came from three different state educational jurisdictions. Each panelist was assigned an identifier, beginning at "A". All 25 panelists responded to the first-round survey (DS1), although one panelist did not complete all questions. Eighteen panelists completed the second-round survey (DS2). These participation rates are consistent with panel participation in a Delphi study and are satisfactory to consider the results valid (Mitroff & Turoff, 1975; Ziglio, 1996).

Table 3.1

Delphi Panelists

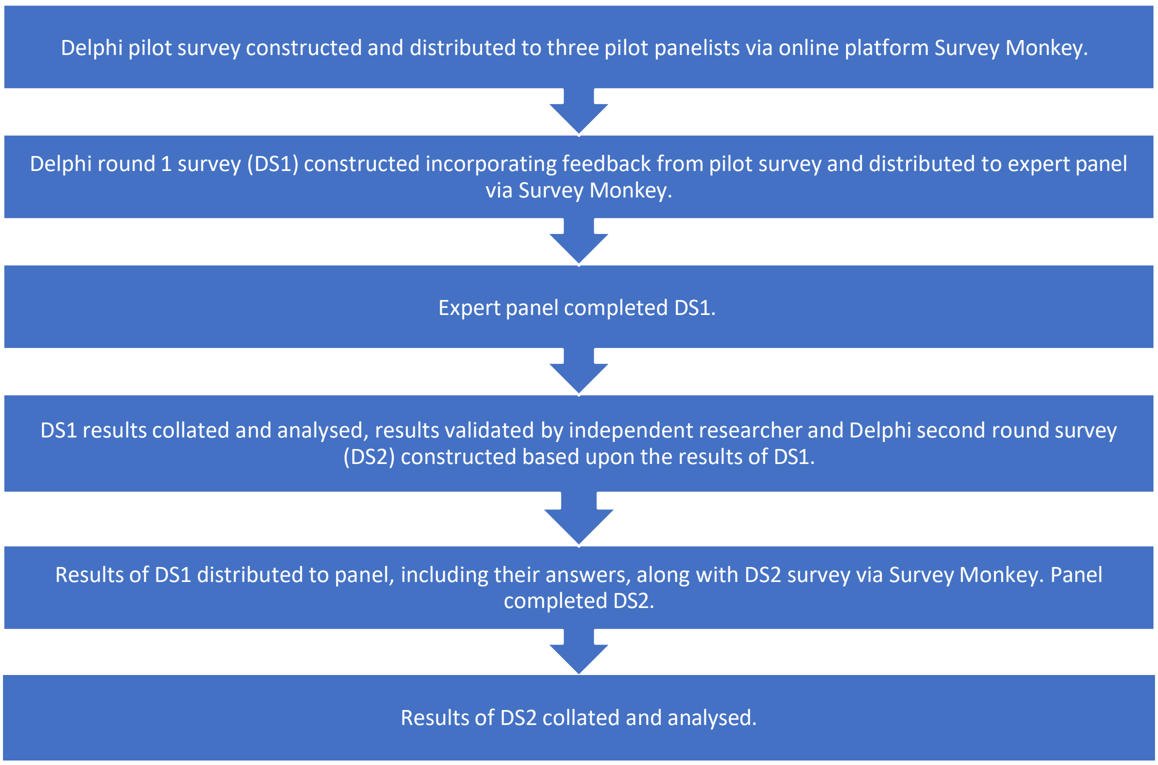
Delphi Panelists		
Education system leaders and policy advisors	6	D; F; M; T; U; Y
Education and/or innovation researchers	8	A; J; P; V; W; R; S; X
School leaders and/or leaders of innovation in schools	11	B; C; E; G; H; I; K; L; N; O; Q;

According to Delbecq et al. (1975) and subsequent interpretations of their work, the number of Delphi iterations, or "rounds" used in a study depends largely on the degree of consensus sought by the investigators and thus can vary between one and six rounds (Skulmoski et al, 2007) although most are restricted to two or three rounds (Day & Bobeva, 2005), with a minimum of two rounds generally considered necessary (Hasson et al., 2000; Thangaratinam & Redman, 2005). In this study, I initially aimed at three rounds of data collection and analysis; however, consensus was achieved on all but one item after two rounds and therefore the study concluded at this point.

Figure 3.1 outlines the protocol used in the study following the expert panel selection, which is a variation on that outlined by Shelton and Creghan (2015).

Figure 3.1

Delphi Protocol Used in This Study



Note. Based on Shelton and Creghan (2015)

3.3.2.1 Round One Questionnaire. In modified Delphi studies, round one involves an initial instrument with a number of items to be rated, ranked, or evaluated by a criterion of importance or significance (Pfeiffer, 1968, in Youseff, 2007), which are then analysed quantitatively. In this study, the round one survey (DS1) contained items developed from the literature review: the initial sets of items to be ranked, and some open-ended questions to identify further items of importance. These items included five summary statements about innovation in education and six features identified as having a constraining impact on schools. DS1 therefore included 11 items for participants to rate their level of agreement using a 5-point Likert scale that used the terms strongly disagree; disagree; neither agree nor disagree; agree; and strongly agree.

These items derived from the literature were included for two reasons. First, in line with the modified Delphi technique used in this study began with a set of carefully selected items drawn from a synthesised review of the literature (Custer et al, 1999), rather than with wholly open-ended questions. This formed the basis on which to spark discussion and commentary from the expert panelists. Second, as part of creating a contemporary definition of innovation in school education, it was important to canvass and retest these aspects of the existing literature with the expert panel. This was because, these definitions were narrower than the scope of this study, having been created in slightly different contexts and/or being out of date in terms of the current political and educational climate. During DS1, the panelists were also asked to (a) provide a definition and commentary in relation to innovation in schools, innovative teaching, and innovative school leadership, and (b) name innovation-fostering and innovation-limiting factors they had witnessed in schools.

The survey instrument intended for use in DS1 was reviewed by teacher education researchers from the University of Technology Sydney for content validity. The survey was pilot tested by three panelists to determine an average timeframe for completion of the instrument, to identify and work out potential problems in understanding or navigation, and to review the survey questions to clarify any confusing items (Mitroff & Turoff, 1975). Modifications to the survey made following these reviews included a slight change in wording of one of the items and the placement of items in a different order. A copy of the final survey instrument used for DS1 is included in Appendix C.

3.3.2.2 Round 2 Questionnaire. Six of the 11 items achieved consensus after DS1 and four were included in the second round (DS2) so that the participants could rate the items again in the light of group feedback. One of these items was slightly re-worded in DS2 to take into account the feedback from DS1. One item was withdrawn after round one as it did not meet the statistical level of agreement and was "not considered a factor" (see Section 3.5.1.3 for the data analysis procedures). During DS1, the panelists were also asked to provide a definition and commentary in relation to innovation in schools, innovative teaching, and innovative school leadership, and to describe any innovation-fostering and innovation-limiting factors they had witnessed in schools. These commentaries were analysed qualitatively using thematic analysis (Brady, 2015). This analysis produced a further 23 items to be ranked in DS2, including the features of innovative teaching, features of innovative school leadership, innovation-fostering factors, and innovation-limiting factors. A copy of the survey instrument used in DS2 is included in Appendix D. At the end of round two, all items except one had achieved consensus and the Delphi study was concluded at this point.

3.3.3 Data Analysis

According to Linstone and Turoff (1975), achieving consensus in a Delphi study involves the process of an expert panel reaching an understanding, either by agreeing or disagreeing on the issue of highlight. A regular and accepted way of determining such consensus is to have participants rank their responses on a Likert scale (Becuwe, 2017). A 5-point Likert scale was used for participants to rate their level of agreement or disagreement with each statement as strongly disagree; disagree; neither agree nor disagree; agree; and strongly agree. Although the use of the Likert scale is accepted, various means of assessing the level of consensus using a Likert scale have been outlined in the literature, and "a common practice to measure it does not exist" (Giannarou & Zervas, 2014, p. 67). Researchers have variously defined consensus and the criteria for determining when it is achieved based on the number of expert panelists, and on the purpose and duration of their study (Nworie, 2011). While there is no accepted best approach, the *certain level of agreement* is often used (von der Gracht, 2012), and it was adopted in this study.

In Delphi studies, measures of central tendency are routinely used to reflect convergence of opinion for the certain level of agreement (Hsu & Sandford, 2007). De Villiers et al. (2005) defined this level of agreement or consensus as “a gathering around median responses with minimal divergence” (p. 639). Pare et al. (2013) found that many studies had used mean rankings for data analysis. Giannarou and Zervas (2014) also found that studies often measured consensus using a standard deviation in addition to the mean. They advised that the standard deviation a rigorous Delphi analysis should be less than 1.5 and include the calculation of the median, because this describes the most typical response as well as the mode, representing the most frequently occurring value.

In this study, I used all these measures to identify the conditions regarded as important by stakeholders in determining a level of consensus for each item. Specifically, the statistical consensus level of agreement with an item used was the mean response score of > 3.50, with a standard deviation < 1.5. The median and mode scores were used as supporting guides. According to Miller (2006), consensus on a topic can be decided if a certain percentage of the votes falls within a prescribed range as identified by the researcher. There is no accepted set standard for the target percentage of agreement (Stewart et al., 2017), with values ranging from 55 to 100 per cent (Powell, 2003); however, Delphi studies frequently use values above 60 per cent to indicate consensus among the panel members with a particular item (Niederberger & Spranger, 2020; Shelton & Creghan, 2015). Various studies suggest that it is important for each researcher to evaluate the responses in the context of the research problem and determine acceptable agreement rates (Boulkedid et al., 2011; Fink et al, 1984; Taylor, 2020).

For this study, I used “percentage votes” as a supplementary guide in deciding agreement in addition to the measures of central tendency. Where other statistical conditions were met, the percentage of the expert participants who rated an item positively (summative of agree and strongly agree) needed to be 65 per cent or more. The statistical level where items where not considered a factor related to innovation in schools was set at < 3.00 and/or with a standard deviation >1.5, and a “percentage agreement” of less than 50 per cent. According to these criteria, participant responses could fall into three possible categories: “agreement”, “needing clarification”, and “not considered a factor”.

In addition to rating each of the items, participants in Delphi studies are often asked to make additional suggestions related to (a) the phrasing of items or (b) ideas about any new items that they believe should be added (Custer, 1999). During the DS1 round in this study, participants were encouraged to provide commentary after the ranking of each item, and were also asked to answer open-ended questions in relation to innovation in schools, innovative teaching, innovative school leadership, and the factors that foster or limit innovation in schools. As is widely recommended within the methodological literature for the Delphi method, I analysed the qualitative data generated by these open-ended questions using thematic analysis (Dalkey & Helmer, 1963; Linstone & Turoff, 1975), wherein the data was examined for concepts, categories, and themes (Brady, 2016).

The participants' responses were examined and coded for commonality and consensus (Brady, 2015). Concepts were identified based on the frequency that the participants discussed them. As Brady (2015) explained, "While concepts are the closest unit of analysis to the original raw data, categories are more abstract … [and] require the researcher to utilise prior knowledge from the literature to identify relationships, links, and other ways to organise concepts" (p. 4). The data was further analysed for explanatory ideas found in the themes (Bazeley, 2009). Subsequently, this data was developed into a set of statements that were categorised and divided into subheadings and used as items for the DS2. The panelists again rated each item on a 5-point Likert scale and were given an opportunity to add comments. Open-ended responses from DS2 were again analysed thematically as outlined above.

At the same time that DS2 was distributed to the panelists, the percentage ranges of items from DS1 were shared with them, along with their own individual answers. Four items from DS1 needed to be ranked again in DS2 as these did not meet the statistical consensus level of agreement and were determined "needing clarification". One item was withdrawn after DS1 as it was "not considered a factor".

3.4 Narrative Inquiry

Following the research in phase one, in which a consensus understanding of school innovation was established, a qualitative approach was taken to examine innovation in K–6 STEM education. In-depth understanding in qualitative research occurs through listening, interpreting, and retelling participants' accounts in a manner that is meaningful (Crotty, 1998; Denzin & Lincoln, 2008). Unlike purely quantitative research, where findings are "arrived at by means of statistical procedures" (Strauss & Corbin, 1990, p. 17), qualitative research produces findings arrived from real-world settings where the phenomenon of interest unfold naturally (Patton, 2001). Broadly defined, qualitative research is the study of phenomena in their natural settings that endeavours to make sense of things in terms of the meanings people bring to them (Denzin & Lincoln, 2000). The phenomenon in this study was innovative teaching and leadership of STEM, the setting was primary schools and school systems, and the sense-making or interpretation involved perceptions and beliefs of and about teachers and schooling.

The qualitative methodology applied in this phase was narrative inquiry. Connelly and Clandinin (1990) were the first to use the term narrative inquiry in educational research, although, as noted above, narrative concepts have a long intellectual history (Polkinghorne, 1995). Narrative inquiry is more than a research approach, "it is a research methodology and a view of a phenomena" (Caine et al., 2013). Moen (2006) goes further to describe narrative research as an all-encompassing framework for study, a "frame of reference, a way of reflecting during the entire inquiry process, a research method, and a mode for representing the research study" (p. 57). Accordingly, in this phase of the study I used research methods, data analysis procedures, and ways of representing the data that aligned with narrative inquiry approach.

By phase two of the research, the narrative inquiry had already begun, as the phase one study was effectively a "prologue" to inform the work of phase two. Further steps in the narrative inquiry involved (a) situating myself as researcher and "narrator" within the study, (b) selecting research participants (characters), (c) data collection, and (d) analysis through "emplotment" (Polkinghorne, 1995).

3.4.1 Situating the Researcher Within the Study

A narrative inquiry collects participants' stories and retells the participants' views by combining the researcher's experience with those of the participants to produce a collaborative narrative (Creswell, 2003). The key here is that narrative inquiry occurs within relationships among researchers and practitioners, constructed as a caring community (Connelly & Clandinin, 1990). This means that narrative inquiry assumes personal involvement by the researcher and is not about "dispassionate chronicling of experiences and events" (Kramp, 2003, p. 114). Therefore, at the outset, I completed what Clandinin et al. (2007) recommend, which is a "narrative beginning" that speaks to a researcher's relationship to and interest in a study. This essentially formed a preface in the story and outlined my experiences, thoughts, and beliefs in relation to schooling, innovation, and STEM education. As it forms part of the narrative, this preface is included in Chapter 1 (Section 1.1).

3.4.2 Selecting the Research Participants

When it comes to the selection of participants in a narrative inquiry, there is a consensus in the literature that narrative research should not be judged by the same criteria as those that are applied to more traditional qualitative and quantitative research methods (Amsterdam & Bruner, 2000; Geelan, 2003; Huberman, 1995; Polkinghorne, 1988; Riessman, 1993; Webster & Mertova, 2007). According to Webster and Mertova (2007),

> Traditional approaches to research tend to be based more on scientific methods, facts and processes. Narrative inquiry and storytelling research ... seeks to elaborate and investigate individual interpretations and worldviews of complex and human-centred events. It is more concerned with individual truths than identifying generalisable and repeatable events. (p. 89)

The purpose of this second phase of the research was to gain further understanding of innovation in a school context and of the institutional, regulatory, and other influences that can enhance or prevent innovation in K–6 STEM learning. That is, my intent was to uncover the story surrounding some innovative approaches to STEM teaching in K–6 schools through the lived experiences of teachers and school leaders – to provide insights rather than to generalise the data to all schools.

Creswell (2013) suggested that an appropriate sample size in narrative research can be as small as one or two participants, unless the researcher is trying to create a collective-participant story. In this study, stories were told by six participants in three case study schools serving differing communities and having varying structures and cultures. The cases consisted of a school site with multiple "characters" as participants, including teachers and school leaders. Criteria sampling (Miles & Huberman, 1994) was employed in the selection of cases. Specifically, to enable a sample that generated rich information on the phenomena of interest, I selected schools that had

- K–6 students,
- a STEM learning program within the school currently and/or STEM learning program within the school in recent past (up to three years), and
- an innovative approach to, implementation of, and/or teaching of STEM.

Applying these criteria, I selected cases that presented the greatest opportunity of enhancing understanding and exploration of the research questions (Stake, 2006). In this regard, selecting the examples that best exemplified innovative teaching and leadership of STEM learning programs (as per the definition that emerged from phase one of the research) was the ultimate deciding factor in the selection of cases. The cases selected were all nominated by peers within their education systems as using (a) innovative STEM learning to build innovation skills in students; and (b) new STEM learning practices considered by their peers as disruptive (see Section 2.1.8), where the meaning of a disruptive practice in an educational context is that it is different from existing practices, initially causes discomfort or could be disparaged, and has the potential to eventually take over or supplant an existing practice (Christensen, 2014; Christensen et al., 2008; Christensen et al., 2013; Law, 2008). I consulted the peers via Twitter and LinkedIn and my own professional learning networks. Each of the schools selected was considered by nominating peers to exemplify the employment of innovative STEM practices that rendered them outliers and risk-takers by colleagues within their systems.

Given that the drive for STEM and innovation skills is a global phenomenon, as is the education reform movement generally, geographical context was not a limiting factor in the selection of cases for phase two of this study. As such, the scope of this phase of the study was extended to multiple sites globally to allow for wider exploration of the research questions (Eisenhardt & Graebner, 2007). The final selection of three schools – one in each of Australia, Ireland, and the US –exemplifies the variation in Western school systems, with the different educational traditions and policies of interest in terms of their impact on innovative approaches to K–6 STEM learning.

Where the Australian and Irish case studies are from government schools, the US school is an independent school in one of the five US state jurisdictions that allow private schools to operate outside of common-core curriculum standards and standardised testing. Two educators were interviewed in each case study school, including the school leader and a teacher. Four men and two women made up the total of six participants or "characters" included in the narratives. Pseudonyms were used for the characters throughout the narratives.

3.4.3 Backgrounds and Contexts of the Three Selected Schools

As outlined in the literature review, Australian governments have embraced the neoliberal education reforms that are widespread in the UK and the US (Savage, 2017), with measures such as changes to school funding, a standard national curriculum, a national assessment to compare and publicly report student performance in literacy and numeracy (Masters, 2020), and national professional teaching standards (Gannon 2012; Mulcahy, 2011; Thomas, 2012). In Ireland, despite some resistance to the dominant global education reform movement, OECD PISA testing has seen an increase in school performance accountability via a culture of audit and standardisation, albeit with a somewhat lower-stakes interpretation (Conway, 2013; Conway & Murphy 2013). The third case study school exemplifies the dichotomy that exists in the US wherein some schools are subject to the standardising, centralising features of reform legislation and others are removed from it.

The three cases selected used an interdisciplinary model of STEM teaching and learning but in quite diverse ways, with one applying an activities-based STEM classroom model, another using a holistic inquiry project or "challenge" based learning model, and the third employing student-driven, play-based tinkering pedagogy (see 2.3.1). Each school's curriculum regime influenced its innovative approach to STEM learning.

Australia has a mandatory national curriculum, and STEM is addressed through the learning areas of Science, Technologies, and Mathematics, and through general capabilities, particularly Numeracy, Information and Communication Technology (ICT) Capability, and Critical and Creative Thinking (Australian Curriculum Assessment and Reporting Authority, 2016). Engineering is not an explicit subject but is addressed in the design aspects of the technology curriculum and often provides a context for STEM learning (Smith et al., 2020). More recently there has been the introduction of coding, and with that there has been a steady progression of STEM learning in K–6 classrooms, although there are concerns about the narrow vision of STEM instruction when it is largely associated with digital learning practices (Fitzgerald et al., 2020). Smith et al. (2020) point out, however, that teachers working in Australia place a high priority on ensuring that STEM learning is meaningful for their students.

Teaching in K–6 schools in Ireland is typically more traditional and heavily influenced by the didactic and restrictive use of learning from textbooks (Bird, 2017), with strong expectations from parents that all of the content in the textbooks will be completed (Delahunty et al., 2021). There are 11 mandatory curriculum subjects in K–6, with compulsory 8.5 hours instruction time to be timetabled weekly for Language and 4 hours and 10 minutes for Mathematics (Delahunty et al., 2021). Science sits alongside history and geography within the grouping of Social, Environmental, and Science Education, with an average of 1 hour per week typically spent on science. There is no specific mention of technology or engineering as subject offerings, with the concept of technology limited to ICT and digital education. Despite a more recent policy agenda towards developing STEM skills (DES, 2017a,b), in reality STEM teaching in Irish schools to date has been informal and extracurricular, dependent on individual teachers or local engagement with enterprise, and including such things as local school projects, visits, exhibitions, science festivals, Science Week, Maths Week, and competitions (Brum & de Oliveira, 2020).

In the US there is no mandatory national curriculum; however, most states have adopted the common core standards initiative that details what students in each grade should know in English and Mathematics and, more recently, the Next Generation Science Standards. While the notion of STEM learning has been embraced, "there is limited evidence of theoretical frameworks and a lack of common language for the design" for STEM integration in K-6 (Baker & Galanti, 2017, p. 2).

3.4.4 Data Collection

According to Clandinin and Connelly (2000), a number of methods of data collection are possible in a narrative inquiry. Data can be in the form of field notes of the shared experience, journal records, interview transcripts, others' observations, storytelling, letter writing, autobiographical writing, documents such as class plans and newsletters, and writing such as rules, principles, pictures, metaphors, and personal philosophies. From among these, I chose the following research instruments as best fitting this phase of the study:

- semi-structured interviews,
- researcher journal entries, and

- documents, including school plans, annual reports, system policies, school websites, government policy and legislation.

Narratives were constructed by triangulating data from these sources (Moen, 2006).

3.4.4.1 Interviews. Prior to being interviewed, the participants were provided with a participant information sheet and consent form (Appendix E), and each consented via email. They were interviewed using Zoom and permission was sought (and granted) for the audio recording of the interviews. Each participant was offered a transcript of their interview.

Kvale (1996) explained that the qualitative interview is a "construction site of knowledge" and literally an "inter-view" (p. 1), which is an interchange of views about a theme of mutual interest in which an attempt is made to understand the world from the subject's point of view. Further, Coffey and Atkinson (1996) suggested that interviews provide rich data that can be interpreted for elements of a narrative and that carefully structured interviews can implicitly and explicitly invite participants to recount stories. Therefore, I carefully constructed the questions in the interview schedule to elicit this type of information (see Appendix F).

It is important to note, however, that the questions in the interview schedule were limited. This is because the interviewing technique used in this study was also informed by Jovchelovitch and Bauer (2000), who argue that the idea of narrative interviewing is motivated by a critique of the question–response schema of most interviews. That is, to elicit a less imposed and therefore more "valid" rendering of the informant's perspective, the influence of the interviewer should be minimal. Therefore, my narrative interview schedule was guided by the narrative structure and contained no formal pre-formulated questions. This was designed to facilitate each participant's using their own spontaneous language in the narration of events.

3.4.4.2 Researcher Journal Entries. In addition to narrative interviews, researcher journal entries can provide a reflective, self-study element to a narrative inquiry (Smith, 2006) and support the collaborative, joint-construction narrative view (Creswell, 2003). That is, narrative inquiry "requires the application of a special kind of mindfulness" (Meier & Stremmel, 2010, pp. 251-252) and thus the adopting of a narrative view of the phenomena of interest "as shaped by a multiplicity of personal and social contexts and conditions” (p. 252). For Connelly and Clandinin (1990), narrative inquirers (researchers) become part of narrative inquiry process and “the two narratives of participant and researcher become, in part, as shared narrative construction and reconstruction through inquiry” (p. 5). They also suggest that researcher journal entries are an important source of data and can assist with the reflexive and recursive process that a narrative inquirer must engage in. Further, a way to ensure trustworthiness in narrative inquiry is via the reflective appraisal of the process of inquiry undertaken by the researcher. As Borg (2001) argues, a research journal deepen a researcher’s understanding of all facets of the research process.

As such, during both phases of the study I kept a journal, recording dated entries in a physical notebook (excerpt included in Appendix G). Many recordings while seemingly practical in nature, for example tracking of contact with participants, in truth worked to provide a research trail making my experiences visible and the thinking behind decisions in the research process transparent (Ortlipp, 2008). Other entries recorded reflections throughout the research process, paying ongoing attention to my experience as a narrative inquirer (Clandinin et al., 2015). These reflections, or interim research texts (Shaw, 2017), became valuable narrative accounts of experiences from the field (Clandinin, 2013; Clandinin & Connelly, 2000). For example, as can be seen from the excerpt included in Appendix G, I recorded my thoughts after each narrative interview was conducted, in this instance enabling me to make links between insights that participants shared, creating further items for analysis. Indeed, Watt (2007) describes this reflection in journalling as the beginning of analysis, and Maxwell (1996) argues that recording these thoughts about the work converts them into a form that allows further examination. By encouraging thinking *with* stories (Morris, 2002) rather than simply about the stories, the journal enabled me to more easily think narratively about the experiences of the participants (Clandinin et al., 2015).

3.4.4.3 Documents. Various scholars have argued that documents are a rich source of data to inform narrative inquiry (Connelly and Clandinin; 2007; Daiute, 2013; Payne & Winsor, 2017; Wilson, 2007; Yamagata-Lynch et al., 2017). In uncovering the stories inherent in each school site, documents can be considered both discursive practices and social artefacts that can be analysed for principles, concepts and tensions involved in the social context in which they are created (Daiute, 2008).   Documents related to each of the case study schools were collected and analysed, including school newsletters, school websites, communications between home and school, planned units of work, school policies, school system policies, media reports about the school(s) as well as government policies and legislation. Each of these were used as field texts adding meaning to the stories told by the participants, providing insight as to the on the values, policies, and ideological perspectives held by various stakeholders (Yamagata-Lynch et al., 2017).

3.4.5 Data Analysis

In narrative inquiry the researcher's task is to configure the data into a story; to develop or discover a plot that displays the connection among the data elements (Polkinghorne, 1995). The analysis of the data in this phase of the research therefore first involved "defining and balancing the commonplaces" (Connelly &Clandinin, 2006, p. 482), however this does not refer to coding and categorising aspects of the different stories. Rather, Polkinghorne (1995) argues that the "process of narrative analysis is actually a synthesizing of the data rather than a separation of it into its constituent parts" (p. 15) which can be achieved via recursive movements from the data to the emerging thematic plot, always testing the story with the data collected. It involves the researcher using the interpretation given by the interviewee while also constructing their own meaning from the narrative (Riessman, 1993). To facilitate this, in examining the interview transcripts in conjunction with researcher journal entries and collected documents I applied some of Labov's (1997, 2007) units of narrative structure, adapted to the purposes of this study, to unpack elements of story in the responses. This is outlined in Table 3.2.

Table 3.2

Labov's (1997, 2007) Units of Narrative Structure

Element	Analysis
Abstract	Beginning. Sparking Interest. Summary
Orientation	Who, what, where, when, why?
Complicating Action	The problem to be solved. And then what happened?
Resolution	What happened next? What finally happened?
Evaluation	What did we learn? So what?
Coda	What is the 'moral' to the story? What does it all mean?

In addition, I used Coffey and Atkin's (1996) notion of "success stories" and "moral tales", with some examples inevitably falling into both categories, along with Denzin's (1989) "epiphanies", to create an emplotted narrative. Denzin proposed four different types of epiphany. A cumulative epiphany is an event that is symbolic of profound changes caused by the accumulation of numerous related experiences. An illuminative epiphany is a particular experience that reveals insights or an event that raises issues that are problematic. A major epiphany is an event or problematic experience that is so challenging that its meanings or consequences are immediate. A relived epiphany is an event or issue where meaning is only understood after reliving it.

In configuring an emplotted narrative or story, I synthesised the events and actions from the different experiences of participants to establish "resonant threads" (Clandinin, 2013) about innovation in K–6 STEM, which were organised as a whole by the means of a plot (Polkinghorne, 1995). I did this by making simple notes about how each of the stories applied these threads, and then by writing and re-storying events in a chronological sequence (Cortazzi, 1993), chronology here signifying a beginning, middle, and end. However, most importantly, as in a novel, these elements involve an issue or conflict, a main character or protagonist, and a plot that ends in resolution (Carter, 1993). This action was completed as a separate story for each school context, including The STEM Room featuring Antony and Frank, Challenge-Based STEM with William and Bella and Student-Led Experiential STEM with Maurice and Phillipa. These stories were then woven into a meta story to illustrate a picture of the status of K–6 STEM learning and include lessons about what fosters and limits innovation and innovative teaching in this space.

In summary, the narrative analysis was conducted via the narrative writing process. However, as Connelly and Clandinin (2007) point out, "at the completion of a narrative study it is often not clear when the writing of the study began" (p. 7) and therefore while a clear process of analysing the data and constructing the narrative was used, the analysis also occurred via the narrative thinking that was used throughout both phases of the study (Moen, 2006). Nevertheless, the more explicit narrative process used involved: (1) transcribing narrative interviews; (2) examining the participant accounts for resonant threads and identified 'success stories', 'moral tales', and 'epiphanies;' (3) reviewing and reflecting on the documents and journal entries to further make sense of the narratives in context (Connelly & Clandinin, 2007); (4) re-storying participant experiences into narratives using units of narrative structure with a beginning, middle and end; (5) carrying out member checks of the details and stories constructed (see section 3.6); (6) emplotting the narratives of each school site; and (7) restorying the findings into a metanarrative to highlight and discuss insights about school innovation and innovative K–6 STEM education in relation to the research questions and the literature.

3.5 Methodological Limitations

Consideration was given to the methodological issues that have been encountered in previous studies using the Delphi method and narrative inquiry. I noted potential problems and took steps to mitigate their impact in the design of this study. Delbecq et al. (1975) proposed that adequate time and high participant motivation are essential for ensuring the success of the Delphi process, and if these factors are attended to, researchers can experience challenges. These issues are linked, in that the Delphi can become time consuming and thus attrition periodically can be a problem (Clayton, 1997; de Villiers et al., 2005; Hsu & Sandford, 2007; Vernon, 2009; Williams & Webb, 1994; Yousuf, 2007). This is especially true if the length of the Delphi leads to "panel fatigue", where panel members become less interested or inclined to participate after each round (Rotondi & Gustafson, 1996; Vernon, 2009). Shelton (2010) suggested taking precautions against this limitation, including by clearly defining the time parameters required for the study. Hasson et al. (2000) recommend selecting expert panelists who have a strong interest in the research study and reminding them of their importance to the outcome of the research. I took both of these measures in this study. Importantly, I also provided individualised feedback to participants after round one to ensure they felt their participation was personally satisfying and enlightening, despite this being a very time-consuming process (Rotondi & Gustafson, 1996). Although there was slight attrition between DS1 and DS2, the number of panel members was still more than satisfactory for the purposes of the study. I kept this limitation in mind when making the decision to conclude the Delphi study as soon as consensus was achieved at the end of round two.

Another limitation I attend to was that the reliability of Delphi processes can be problematic (Vernon, 2009), in that the questions can be interpreted differently by different panel members, impacting the accuracy of the results (McMillan, 2004). In addressing this limitation Ziglio (1996) suggested that giving clear instructions to the expert panel can help clarify any ambiguities and increase the reliability of the responses. In this study, I conducted a pilot study of the DS1 questionnaire to ensure that the questions distributed to the expert panel were clear, easily read, and unambiguous. In order to increase the clarity and reliability of the research, the suggestions made by the experts in this pilot study were implemented prior to the distribution of the round one survey instrument to the expert panel. In addition, between rounds one and two I changed the wording of a question in response to panel feedback.

The perspectival nature of stories is a potential limitation in the use of narrative as research data (Greenhalgh et al., 2005). As such, "a different interviewer on a different day will never be able to collect the 'same' story from a respondent" (p. 444). My challenge here was not to control for but to capture the inherent subjectivity, inconsistency, and emotionality of stories as data and interpret them appropriately. There should also remain the recognition that "we do not find stories; we make stories" (Mishler, 1995, p.117), in that by retelling participant's accounts through analytic redescriptions the researcher is reconstructing the story and therefore in this sense the story is co-authored. However, in this study, I took measures to accurately capture the participants' own voices by using a semi-structured interview schedule, with no pre-formulated questions. Again, this was to elicit a less imposed rendering of the participants' perspectives with minimal interviewer influence. I also offered the interview transcripts to participants for checking, to ensure they saw that their insights were being accurately recorded and portrayed. Where there were items that needed clarification after interviews, I contacted the relevant participants to ensure accurate re-creation of their experiences.

3.6 Trustworthiness

Establishing trustworthiness in a study relies on methodological procedures being adhered to. Hasson and Keeney (2011) noted that this can be problematic in Delphi studies as different forms of the technique have evolved over time, resulting in varying interpretations of the technique. In addition, given that the modified Delphi methodology adopted in this study overlaps both the quantitative and qualitative ideals, I used the accepted approach outlined in a number of studies that nominate the qualitative construct of trustworthiness as more appropriate than reliability and validity in gauging the effectiveness of a study (Brady, 2015; Cornick, 2006; Day & Bobeva, 2005; Hasson & Keeney, 2011; Holloway & Wheeler, 1996). As such, I established the trustworthiness in this phase of the research using Lincoln and Guba's (1985) criteria of trustworthiness in qualitative research: credibility, transferability, dependability, and confirmability.

Although by its very definition the modified Delphi is a modification of a methodological approach, credibility in a study can be maximised by ensuring that the formulation of the method's architectural components are based on existing models (Day & Bobeva, 2005). In this study, credibility was also ensured by the number and quality of knowledge of the participants, and the member checking that is inherent in the methodology with the use of successive rounds of the questionnaire (Hasson et al, 2000).

Transferability of findings to other contexts and settings was ensured by reporting the methods and findings to allow for what Lincoln and Guba (1985) call "thick description." That is, this modified Delphi study developed transferability through a detailed description of all methods of data collection and analysis, while the rich description in the findings allowed for via the design of the open-ended questions. In addition, an internal audit (Lincoln & Guba, 1986) of the quantitative data and methods was carried out by an independent "disinterested" member of the university academic staff.

Dependability refers to refers to the stability of data collected. It was achieved in this Delphi study by including a range of participants (Cornick, 2006), all of whom were experienced individuals familiar with the phenomena (Day & Bobeva, 2005). In addition, the process of developing the instrument was documented and auditable, adding to the dependability of the Delphi study (Day & Bobeva, 2005; Engels & Kennedy, 2007). Confirmability rests on consistent and systematic data collection, coding, and analysis (Engels & Kennedy, 2007), and it was achieved in this study by maintaining a detailed description of the Delphi collection and analysis process (Hasson & Keeney, 2011).

Further, the study meets Pare et al.'s (2013) four criteria for establishing trustworthiness in Delphi studies. First, by ensuring the anonymity of participants, the difficulties associated with group dynamics, such as manipulation and coercion to conform or adopt a certain viewpoint, were avoided. Second, I reported the response rate to the initial call for participation, which was 25 out of 30. Reporting the response rate is important because a low rate might indicate that potential expert participants do not consider the study relevant or important (Schmidt, 1997). Third, I reported the panel size, which fitted well within the optimal size indicated in the literature, even after round two attrition. Finally, the trustworthiness of the Delphi study was enhanced by my piloting and pre-testing of the task instructions and questionnaire instrument, which helped to avoid confusion and ambiguity.

Narrative research scholars have noted that issues of trustworthiness must be attended to differently in the case of narrative inquiry, both in comparison to positivist styles of research and to other forms of qualitative research (Connelly & Clandinin, 1990, 2006; Clandinin & Connelly, 2000; Clandinin et al., 2007). Criteria to determine trustworthiness in narrative research can be considered in conjunction with those more widely accepted in qualitative research (Loh, 2013). As such, rigour in this phase of the study was again confirmed using Lincoln and Guba's (1985) criteria of trustworthiness in qualitative research, namely, credibility, transferability, dependability. and confirmability.

According to Shenton (2004), one of the mechanisms to ensure credibility is establishing operational measures within the qualitative research methodology used. That is, "the specific procedures employed, such as the line of questioning pursued in the data gathering sessions and the methods of data analysis, should be derived, where possible, from those that have been successfully utilised in previous comparable projects" (p. 64). In this study, the data collection methods and analysis followed procedures that are well established in the literature, as outlined earlier in this chapter. Credibility was further ensured by employing what Lincoln and Guba (1985) refer to as "member checks" and "triangulation." Member checking was carried out with follow-up contact subsequent to each interview to solicit reactions to the reconstruction of the stories uncovered in the interviews. I also shared or offered to share (this option was not always taken up by the participant) the transcript of the interview with each participant to ensure confidence in the accuracy of the recording of the interview.

Shenton (2004) outlined that one form of triangulation is via data sources, specifically the use of a range of informants so that "individual viewpoints and experiences can be verified against others and, ultimately, a rich picture of the attitudes, needs or behaviour of those under scrutiny may be constructed based on the contributions of a range of people" (p. 66). As mentioned earlier, in this study I also used a distinct case school from each of three international contexts, with two teacher participants in each case school; hence, corroboration was achieved by comparing the needs and actions described in each case.

According to Merriam (1998), transferability is concerned with the extent to which the findings of one study can be applied to other situations, and qualitative research cannot be compared with positivist research where the concern lies in demonstrating that results can be applied to a wider population. With respect to narrative research, "the narrative inquirer does not prescribe general applications and uses but rather creates texts that, when well done, offer readers a place to imagine their own uses and applications" (Clandinin & Connelly, 2000, p. 42).

As outlined earlier, the intent of this narrative inquiry was to uncover the story of some innovative approaches to STEM teaching and learning in K–6 schools through the lived experiences of teachers and school leaders by providing insights rather than by generalising the data to all schools. However, the transferability of the findings of this research was a consideration in the design of the study. Lincoln and Guba (1985) suggested that in qualitative studies, it is the responsibility of the researcher to share the findings in such a way that the reader can apply the learnings to another context. That is, by including rich descriptive data, as in this study, a narrative can be developed "so that the judgements about the degree of fit or similarity may be made by others who may wish to apply all or part of the findings elsewhere" (Lincoln & Guba, 1986, p. 77). In addition, Shenton (2004) has argued that "the same methods but conducted in different environments could well be of great value" (p. 70) in establishing transferability in a study. In this study, the highlighting of the stories of STEM learning innovation in different K–6 school contexts was intended to assist the reader in understanding how the findings can apply across settings.

Issues of dependability in a study should be addressed by reporting in detail the research processes used, allowing the reader to assess their appropriateness (Shenton, 2004). This methodology chapter accomplishes this with its description of the research design and its implementation. In this study, I reinforced dependability by maintaining an in-depth account of the operational details of data gathering and analysis, including transcribed interview notes, and notes detailing the process of analysis and coding. In addition, throughout the study I kept a journal with reflective appraisals of the project, which assisted my evaluating the effectiveness of the research process.

Miles and Huberman (1994) outline that key to establishing confirmability in a qualitative study is the extent to which the researcher admits his or her own predispositions. As outlined earlier in this chapter, at the beginning of the Chapter 1, I include what Clandinin et al. (2007) call a narrative beginning that speaks to my relationship to and interest in the study. This outlines my experiences, thoughts, and beliefs in relation to schooling, innovation, and STEM education, thereby acknowledging how these experiences and beliefs underpinned the decisions I made and methods I adopted. This reflection continued throughout the narrative inquiry process via my research journal.

3.7 Ethics

In this study, I adhered to the University of Technology Sydney's Responsible Conduct of Research and the National Statement on Ethical Conduct in Human Research by securing ethical approval from UTS Human Research Ethics Committee (HREC), approval number ETH18-2833, before proceeding (see ethics approval Appendix H). For phase two of the study, I received approval from the NSW State Education Research Application Process (SERAP) (see Appendix I). Approval outside individual consent was not necessary for the other stakeholder groups.

As outlined by Caine et al. (2013), "the first responsibility of narrative inquirers is always to participants. The negotiations of entry and exit, as well as the representation of experience, are central ethical concerns" (p. 579). As such protection of participants was paramount, or both phases of the study, all participants were accorded respect and protection of data and provided complete anonymity in the data collection and analysis processes. To ensure anonymity, the participants' identities and responses remained confidential. For phase one of the study, de-identified responses were shared between participants in order to reach consensus, but I was the only person with access to the raw data. In phase two, to maintain anonymity I applied a pseudonym to each teacher and school and/or school system to provide confidentiality. Following UTS protocols, I have also ensured that the data from both phases is stored securely and is safe from unauthorised access for a limited time.

Participation in this study was the voluntary choice of the participants after they received sufficient information and an adequate understanding of the research and the consequences of their participation. In guaranteeing informed consent, each participant was provided with detailed information about the study, its aims, and risk of harm via the participant information sheets (see Appendices B and E). For the Delphi study, a mechanism at the beginning of the online survey allowed participants to agree to informed consent, and participants provided written agreement via email for the narrative inquiry. The participants were advised that they could end their participation and withdraw from the study for any reason and at any point in the study.

3.8 Conclusion

The purpose of this study is to add to the literature by telling the story of innovation in K–6 STEM learning. This chapter has outlined the study's design and research methodology. In summary, I navigated the rhetoric about innovation by asking experts in the field via a robust Delphi study to define exactly what innovation is in a school context, and to elucidate the factors that limit and enhance innovative teaching and innovative school leadership. With this fresh and contemporary understanding of innovation in schools, I then examined stories collected globally about K–6 STEM learning innovation, which I used to construct a narrative about the factors that foster and limit innovation and innovative teaching in this space. The next chapter presents the findings of the study in narrative form.

Chapter 4:

Findings

> As we make our way through life, we have continuous experiences and dialogic interactions both with our surrounding world and with ourselves. All of these are woven together into a seamless web, where they might strike one as being overwhelming in their complexity. One way of structuring these experiences is to organise them into meaningful units. One such meaningful unit could be a story, a narrative. For most people, storytelling is a natural way of recounting experience, a practical solution to a fundamental problem in life, creating reasonable order out of experience. (Moen, 2006, p. 56).

> Narrative is an ancient product of human culture that keeps producing cultural innovations (Daiute, 2013 p. 2)

In Chapter 3, I outlined the methodology used in this study in addressing the research questions. I described the pragmatic sociocultural approach underpinning the research design within a narrative inquiry framework. This chapter outlines the findings from both phases of the research. In line with Clandinin and Connelly's (2000) approach to narrative inquiry, which encourages a narrative presentation of results, as well as the narrative processes involved in collecting data, the findings are presented in narrative format. The chapter therefore begins with a prologue that presents the findings of the phase one Delphi study to establish the criteria upon which the data about innovative teaching and leadership in STEM was analysed. This is followed by the stories that describe the findings from each school site.

4.1 Prologue – Innovation in Schools

> From a narrative view of experience, we attend to place, temporality, and sociality within our own life stories and within the experiences of participants. Within this space, each story told and lived is situated and understood within larger cultural, social, familial, and institutional narratives (Caine et al., 2013, p. 577)

> There are two dimensions to the school innovation issue. The first pertains to the capabilities required by young people to have a successful life and also to contribute to economic, social, and their individual wellbeing. The second dimension pertains to what needs to be done to align the nature and structure of school with contemporary culture. (Bosco, 2010 p. iii)

4.1.1 Delphi Panel Process

A panel of 25 experts participated in a Delphi study to answer the research questions How is school innovation defined by experts in the field? and What are the factors that foster and limit innovation in schools? They included six education system leaders and policy advisors, eight education and/or innovation research personnel, and 11 school leaders and/or leaders of innovation in schools, with 14 panelists from Australia, five from the US, and six from Europe. The Australian respondents come from three different state educational jurisdictions. Results from the Delphi study were derived from analyses of quantitative and qualitative data over two rounds of online surveys.

The first round Delphi survey (DS1) included 11 items for participants to rate their level of agreement or disagreement with each statement using a 5-point Likert scale: strongly disagree; disagree; neither agree nor disagree; agree; and strongly agree. These items included five summary statements from the literature about innovation in education (Table 4.1) and six items identified from literature as having a constraining impact on schools (Table 4.4). As explained in Section 3.3.2.1, these items were derived from literature in order to spark discussion and commentary from the expert panelists and to canvass and re-test these aspects of existing literature in terms of the current political and educational climate. Six of the 11 items achieved consensus after DS1 and four were included in the second round Delphi survey (DS2), providing the opportunity for participants to rate the items again in the light of group feedback. One item did not meet statistical conditions of agreement after round one. After both rounds, nine of the 11 items originally included in DS1 achieved consensus.

During DS1, the panelists were also asked to provide a definition and commentary in relation to innovation in schools, innovative teaching, and innovative school leadership. They were also asked to name innovation-fostering and innovation-limiting factors they had witnessed in schools. I analysed this commentary qualitatively, using thematic analysis involving the identification of concepts and categories, moving from specific ideas found in participant responses to less specific but more explanatory ideas found in themes, and relating these to prior knowledge and ideas from existing literature (Brady, 2015). This analysis produced further 23 items to be ranked in DS2, including the features of innovative teaching (Table 4.2), features of innovative school leadership (Table 4.3), innovation-fostering factors (Table 4.5) and innovation-limiting factors (Table 4.6). A consensus was reached on all 23 items. Several items from panel commentary have also been included as quotes throughout the following sections.

4.1.2 Consensus Understandings

4.1.2.1 Innovation in Schools. In the first section of the Delphi round 1 survey (DS1), I asked the expert panelists to rank their level of agreement with five items and to provide commentary in relation to these items. As outlined in the methodology chapter, the statistical consensus level of agreement with an item used was the mean response score of > 3.50, with a standard <1.5. The median and mode scores were used as a guide in supporting these scores. Percentage votes were used as a supplementary mechanism in deciding agreement in addition to the measures of central tendency. Where other statistical conditions were met, the percentage of the experts who rated an item positively (agree and strongly agree) needed to be 65 per cent or more.

The items and the results of these items are displayed in Table 4.1. Results from the first round showed that three items reached consensus and two items did not reach consensus. Following DS1, participants were provided with the results of the survey as part of the Delphi feedback process. This included the group percentage rank along with their own rank of each item. The two statements that did not reach consensus were presented to the participants again in DS2, providing an opportunity for them to reassess their initial judgments. One item was slightly re-worded in DS2 to take into account the feedback of expert panelists in DS1. Following DS2, all five statements achieved consensus.

Table 4.1

Participant Ratings of Summary Statements About Innovation in Education

Survey Item	SA and A %	Mean	Median	Mode	STD DEV	Consensus
						DS1 (n=25)
Innovative teaching involves emerging practices that change what teachers and students do and learn in the classroom.	80	4.0	4.0	4.0	1.15	Agreement
Innovation is both a process and an outcome.	76	4.0	4.0	5.0	1.22	Agreement
Innovation is a process used by educators in response to challenges or changes or to pursue a vision.	68	3.9	4.0	5.0	1.30	Agreement
Educators are charged with creating an innovative future workforce.	64	3.6	4.0	4.0	1.22	Needing clarification
Innovative teaching is both the practice of teaching for creativity and of applying innovation to teaching.	60	3.8	4.0	4.0	1.05	Needing clarification

I combined the statements about innovation in schools that achieved consensus, supported by a qualitative analysis of the open-ended responses provided by panelists in both DS1 and DS2 (see Section 3.3.3), to construct a contemporary consensus understanding of innovation in schools:

> Innovation in schools is a process and an outcome. It is predominantly a process or innate response used by educators in the face of challenges or changes or to pursue a vision. Educators are charged with creating an innovative future workforce and therefore innovative teaching in schools is multilayered. It involves applying innovation to teaching (the process) and is also the practice of teaching to build innovation skills in students (the outcome).

Just as innovation is a process and a product or outcome beyond a school environment (Crossan & Apaydin, 2010), and within an education environment (Ferrari et al. 2009; Hargeaves, 1999; Jeffrey, 2006; Kozma & Anderson, 2002; Langworthy et al. 2011; Mirzajani et al., 2016), the panelists agreed that innovation is both a process and an outcome in schools whose key aspect is the emphasis on "doing new things" (Panelist A). Several panelists viewed the innovation process in schools as a learning process itself, with one stating in relation to innovative teaching: "Some innovative things I do, don't have spectacular outcomes but I learn and students learn for future endeavours" (Panelist V). Another panelist made a similar statement: "The learning garnered from the process is as valuable as the outcome itself " (Panelist Q). This innovation as a learning process analogy will be explored further in the discussion chapter.

Hargreaves (1999) proposed that innovation happens in schools in response to challenges or changes, and Tytler et al. (2011), citing the work of Smith (2005), built on this to include that innovation can be motivated by the pursuit of a vision. The panelists agreed with this definition, with one panelist commenting, "An innovative mindset is a characteristic of vision-led leaders who continually seek improvement" (Panelist S). I noted that innovative teachers and school leaders do not necessarily think of innovation as a method, but rather a "response to achieve an objective by a route not considered previously" (Panelist D). This response can be as described as a natural, automatic, or preferential reaction or action of an educator – an instinctively preferred pathway in approaching teaching or leadership. An interesting theme that emerged in the panel responses is that while innovation is often motivated by a realisation that change is required to "create value," (Panelist P) innovation can also be a creative intellectual process "used by educators for different reasons at different times without necessarily being motivated by a specific need" (Panelist D).

The panelists' commentary added to the definitions proposed by Ferrari et al. (2009) and Mirzajani et al. (2016) that teaching should be shaped by innovations and should also train students to produce innovations, and that innovative teaching is the implementation of new methods, tools, and contents which could benefit learners and their creative potential. More specifically, the panelists agreed that innovative teaching is both the practice of teaching for creativity and the practice of applying innovation to teaching. Applying innovation to teaching means using innovative methods or practices in teaching, as will be explained below in the definition of innovative teaching. However, there was a recognition by the panelists that innovative teaching is "not just about doing something different" (Panelist C) but that the process of innovative teaching leads to the development of skills that assist in nurturing innovation in students. The panelists commented that "innovative teaching involves learning" (Panelist T) (innovation as a learning process as discussed above) and that innovative teaching "models to students the importance of inquiry, which then builds on the creativity and intuition of the children in the classroom" (Panelist J).

While the panelists agreed that educators are charged with creating a future innovative workforce (Hargreaves, 1999; OECD, 2015a; 2016), some commented that this should not be the primary focus or objective of teachers. The broad sentiment of the commentary was that schooling should be thought of in terms of social democratic ideals rather than economic purposes. One panelist made the point that the role of educators and schools is to "teach people how to think and learn" (Panelist N) rather than specifically to build innovation skills and capabilities in students for future jobs, and that "the workforce is being shaped outside of the school" (Panelist O). Other panelists commented that while schools need to "assist, nurture and support students to develop the skills for a current and future lifestyle of contentment and fulfilment" (Panelist L), teachers are "not solely responsible for the success of future economy" (Panelist J). Another commented that building an innovative workforce involves "schools being part of an ecosystem with governments, employers, industry and higher education" (Panelist X). The emphasis in the commentary was on "teaching skills for life in the 21st Century" (Panelist D) rather than specific workforce skills.

Further, while they acknowledged that schools play a role in developing skills for future innovators, they noted that "innovation happens regardless," (Panelist W) as illustrated by the fact that "the current workforce is doing jobs that no one anticipated would exist when those employees were at school" without a specific focus on building these skills in the past, and that education policy makers and indeed educators can perhaps "overreach on this factor" (Panelist Y).

Despite this commentary, there was agreement that building innovation skills is an important outcome of innovative teaching and innovation in schools. The findings in relation to innovation as an outcome in schools will be further explored in the discussion chapter.

4.1.2.2. Innovative Teaching. I analysed the commentary from DS1 in relation to innovative teaching qualitatively using thematic analysis, as outlined in the methodology chapter. I identified six items as features of innovative teaching. These items were then tested in the online survey for DS2, in which the panelists were asked to rank their level of agreement that the items are features of innovative teaching. All six items reached consensus, as outlined in Table 4.2.

I combined the statements about innovation in schools that achieved consensus, supported by a qualitative analysis of the open-ended responses provided by panelists in both DS1 and DS2 (see Section 3.3.3), to construct a contemporary consensus understanding of innovation in schools:

> Innovative teaching involves trying new teaching practices. These practices change what teachers and students do and learn in the classroom. The new practices can be emerging, including trying new ways to support technology enhanced learning, and involve engaging with education research. They can also build on positive and effective existing practices and draw from historic thinking. Innovative teaching often involves using a problem-solving or design approach to seek improvement in student learning outcomes and to promote creative, critical, or problem-solving thinking.

Table 4.2

Participant Ratings of Summary Statements about Innovation Teaching

Survey Item	SA and A %	Mean	Median	Mode	STD DEV	Consensus
						DS2 (n=18)
Involves trying new teaching practices.	89	4.4	4.5	5.0	0.70	Agreement
Allows for learning experiences that promote creative, critical or problem-solving thinking.	83	4.4	5.0	5.0	1.09	Agreement
Seeks improvement in student learning outcomes.	83	4.3	5.0	5.0	1.08	Agreement
Involves engaging with education research.	78	4.0	4.0	4.0	1.03	Agreement
Involves trying new ways to support technology enhanced learning.	78	4.0	4.0	4.0	1.03	Agreement
Uses a problem solving or design approach.	78	4.0	4.0	4.0	1.14	Agreement

These quantitative results were combined with the qualitative analysis of the commentary provided by panelists in both DS1 and DS2 to construct a contemporary consensus understanding of innovative teaching. Emphasised in the panelists' commentary was that innovative teachers adapt their teaching. This involves "changes to ideas, approaches and practices at a classroom level to create teaching and learning experiences that are new in that context" (Panelist I). According to the panelists, innovative teachers use data and respond to individual students or different groups of students, "reviewing and adapting teaching methodologies and resources to ensure that students are engaged and challenged in their learning" (Panelist Q). They take risks, reflect, provide and receive feedback to "improve what they do and when" (Panelist

X). Some innovative teachers are considered disruptive and counter-cultural, "challenging the status quo", and others find ways to innovate within the existing parameters of the different system and policy contexts. According to one panelist,

> Innovative teachers generally find a way around most hurdles that limit possibilities. It may not always involve technology, it may not involve educational research, it may not require leadership by senior management. Sometimes it just requires the enthusiasm of a teacher willing to try something different to increase student learning outcomes (Panelist D).

Panel commentary again reinforced that innovative teaching involves not just new practices, but also nurturing the creative potential in students. Innovative teaching in this context was described as "getting students to think outside the box" (Panelist C) and allowing students "the opportunity to inquire, innovate, make and create" (Panelist B). When referring to improvement in student learning outcomes, several panelists clarified that this improvement meant seeking new ways to engage and enhance the learning of students. One panelist commented that improved student learning outcomes should refer to "improved skill or understanding that is not necessarily linked to improvement in test scores" (Panelist K).

4.1.2.3. Innovative School Leadership. Commentary from the open-ended questions in DS1 in relation to innovative school leadership was also analysed qualitatively using thematic analysis as outlined above. As a result of this analysis, I identified nine features of innovative school leadership. These items were tested in the online survey for DS2, in which the panelists were asked to rank their level of agreement that the items are features of innovative school leadership. All nine features reached consensus, as outlined in Table 4.3.

Table 4.3

DS2 Participant Rankings of Features of Innovative School Leadership

Survey Item	SA and A %	Mean	Median	Mode	STD DEV	Consensus
						DS2 (n=18)
Encourages adaptation and experimentation in teaching practices.	94	4.7	5.0	5.0	0.75	Agreement
Is inquisitive.	94	4.4	5.0	5.0	0.98	Agreement
Overcomes barriers from system requirements (curriculum, assessment, funding) and 'finds a way.'	94	4.4	5.0	5.0	0.98	Agreement
Exhibits professional trust in teachers.	89	4.7	5.0	5.0	0.84	Agreement
Shapes a culture where mistakes are learning opportunities.	89	4.4	5.0	5.0	1.04	Agreement
Is visionary.	89	4.5	5.0	5.0	1.04	Agreement
Pushes boundaries, moving away from norm and convention.	89	4.1	4.0	4.0	1.23	Agreement
Aims for improvement.	83	4.5	5.0	5.0	0.79	Agreement
Applies a creative mindset.	83	4.3	5.0	5.0	1.07	Agreement

I used these results to construct a consensus understanding of innovative school leadership:

> Innovative school leaders exhibit professional trust in teachers. They shape a culture where mistakes are learning opportunities and encourage adaptation and experimentation in teaching practices. Innovative school leaders are visionary, inquisitive and apply a creative mindset, often pushing boundaries and moving away from norm and convention. A key feature demonstrated by innovative school leaders is that they can find solutions to overcome barriers created by external factors, such as mandated curriculum, standardised assessment and funding restrictions.

While the panel experts reinforced the aspect of innovative leadership that centres on the ability and desire for a school leader to drive and facilitate change, substantial themes around trust and support also emerged from the panel commentary in relation to innovative leadership within a school. That is, the experts described innovative leadership as "flexible and courageous" (Panelist V), "challenging the conventions and breaking the rules of the normal paradigm" (Panelist L), and "pushing the boundaries and exploring with limitless possibilities" (Panelist B). However, much of the data in the Delphi study emphasised innovative leadership as having "trust in doing education differently" (Panelist E); acting in ways to "empower teachers, remove obstacles, remove roadblocks for others to shine" (Panelist P); and never tap the breaks" (Panelist V) on innovative teachers.

A "commonplace" (Connelly & Clandinin, 2006) among the experts' responses was creating a culture of professional growth wherein an innovative leader can be seen to provide a "structural framework for teachers to grow their professionalism as pedagogues" (Panelist Y). This can involve "understanding the gifts and talents of every staff member and using those to create an environment that is ripe for learning" (Panelist T); "encouraging the practices of reflection and giving and receiving feedback" (Panelist X); and providing "permission for teachers to design creative learning experiences, research new ideas, and take risks" (Panelist P).

Other commentary echoed these sentiments, elaborating that innovative leadership can mean "being flexible and supporting others to change mindsets" (Panelist B);

providing teachers with “the freedom, resources and supports necessary to innovate” (Panelist D); and allowing “time and space for teachers to explore and problem-solve” (Panelist M). While it was uncovered that vision-led innovative school leaders often aim for improvement, the panel commentary explained that this improvement is not necessarily linked to improvement as measured by student scores in standardised tests.

4.1.3 Factors That Affect School Innovation

4.1.3.1. Innovation-Limiting factors. In the online survey for DS1, the experts were asked to rank six items that were identified in literature as having a constraining impact on innovation in schools. These items and the results are outlined in Table 4.4. Three items reached consensus and two items did not reach consensus and were therefore presented to the participants again in DS2 after the feedback from DS1. One item did not reach the level of agreement during DS1 for it to be considered a factor, as the percentage level agreement was less than 50 per cent. Of the two items retested in DS2, one item reached agreement among the panelists and another item did not reach agreement.

The four items concerning innovation constraining factors that achieved consensus after the two rounds of the Delphi study were (a) prescriptive mandatory curriculum, (b) high stakes standardised testing, (c) top-down (system or school) prescriptive teaching programs, and (d) systems of accountability, such as school inspections. Among these the item with the highest consensus ranking was prescriptive mandatory curriculum, which the panelists indicated can “lack inclusivity, minimise differentiation and limit creative design” (Panelist M). Despite the commonly expressed sentiment that innovative teachers and school leaders are able to overcome constraining and limiting factors, the panelists commented: “If educators are under pressure to achieve prescriptive curricular goals, they are less likely to experiment with innovative teaching techniques” (Panelist Q), and “Innovation comes down to the practitioner, but a crowded curriculum can make people time-poor” (Panelist L). Panelist commentary in relation to high-stakes, standardised testing largely centred on the idea that the tests only become problematic “if leadership allows the tests to set the agenda” (Panelist S). Some panelists commented that by its definition, standardisation is “anti- innovation” (Panelist V) and that “knowing where an individual is located with regard to a standard model does not indicate innovation skills or abilities” (Panelist R).

Table 4.4

Participant Ratings of Items Identified in the Literature as Having a Constraining Impact on Schools

Survey Item	SA and A %	Mean	Median	Mode	STD DEV	Consensus
						DS1 (n=24)
Prescriptive mandatory curriculum can constrain innovation in schools.	75	4.1	4.0	5.0	0.97	Agreement
High stakes, standardised testing can constrain innovation in schools.	71	4.2	5.0	5.0	1.05	Agreement
Top-down prescriptive teaching programs can constrain innovation in schools.	67	4.0	4.0	5.0	0.93	Agreement
Systems of accountability, such as school inspections, can constrain innovation in schools.	54	3.7	4.0	5.0	1.12	Needing clarification
Quality assurance reforms to make teaching practice more consistent, for example teaching standards, can constrain innovation in schools.	50	3.5	3.5	3.0	1.02	Needing clarification
Age-based student cohorts can constrain innovation in schools.	42	3.3	3.0	3.0	1.17	Not considered a factor

Survey Item	SA and A %	Mean	Median	Mode	STD DEV	Consensus
						DS2 (n=18)
Systems of accountability, such as school inspections, can constrain innovation in schools.	67	3.7	4.0	4.0	0.96	Agreement
Quality assurance reforms to make teaching practice more consistent, for example teaching standards, can constrain innovation in schools.	62	3.7	4.0	4.0	0.83	No agreement

In addition to these items, I used thematic analysis to qualitatively analyse the panelist commentary from the open-ended question in DS1 in relation to constraining factors. I identified five items as innovation-limiting factors in schools. These items were tested in the online survey for DS2, in which the panelists were asked to rank their level of agreement with each statement. All five items reached consensus, as outlined in Table 4.5.

In total, the Delphi study determined nine factors that inhibit innovation in schools. Despite this, as included in the definition of innovative leadership, many of the panelists commented that innovative teachers and school leaders can typically find a way to navigate and mitigate limiting and constraining factors in order to be innovative in schools. As one panelist noted,

> Innovative teachers can be slowed, but rarely stopped. Individual constraints can be seen as more of a nuisance and challenge. Truly innovative teachers overcome most obstacles, using their innovation skills to circumvent these challenges (Panelist D).

Table 4.5

Participant Ratings of Innovation Limiting Factors

Survey Item	SA and A %	Mean	Median	Mode	STD DEV	Consensus
						DS2 (n=18)
Lack of support from leadership (within and/or beyond the school).	95	4.3	4	4	0.75	Agreement
Micro-management by leadership within the school.	83	4.4	5	5	0.92	Agreement
Excessive compliance requirements.	83	4.2	4	4	0.86	Agreement
Lack of learning culture within the school.	83	4.0	4	5	1.33	Agreement
Insistence on complete consistency in and between teams of teachers.	72	3.9	4	4	0.73	Agreement

4.1.3.2 Innovation-Fostering Factors. DS1 included an open-ended question inviting commentary about factors fostering or enabling innovation in schools. This commentary was analysed qualitatively, and all responses categorised into eight themes which were constructed into items for ranking in DS2. As outlined in Table 4.6, all items rated in DS2 achieved consensus.

Table 4.6

Participant Ratings of Innovation Fostering Factors

Survey Item	SA and A %	Mean	Median	Mode	STD DEV	Consensus
						DS2 (n=18)
Innovative leadership by the principal	94	4.67	5	5	0.59	Agreement
A culture of creativity and risk taking within the school.	94	4.44	5	5	0.98	Agreement
Enthusiasm of teachers.	89	4.44	5	5	0.70	Agreement
Teacher autonomy	89	4.06	4	4	0.94	Agreement
A culture of inquiry and exposure to education research and ideas.	83	4.06	4	4	1.00	Agreement
Aptitude and skill of teachers.	78	3.89	4	4	1.08	Agreement
Funding for professional learning and collaboration	72	3.94	4	4	1.06	Agreement
Funding for technology	67	3.56	4	4	1.15	Agreement

Innovative school leadership by the principal reflects what was outlined in the definition described earlier in this chapter. The panelists commented that this leadership can be used to motivate change through modelling, to overcome barriers to innovation presented by external factors, and to create conditions and use resources to support teacher creativity, for example, enabling "unstructured time for teachers to be creative (time off the timetable to do cross-curricular teaching) and cross-pollination of staff in offices (not an English office, mathematics office etc)" (Panelist E). A culture of creativity and risk-taking that fosters innovation was described by respondents as embodying “open- minded management” (Panelist W) that acknowledges and rewards innovation and demonstrates “permission from the leadership to break the rules of convention” (Panelist L); an “attitude of encouragement to non-conformists” (Panelist K); and “a spirit of taking on the established norms” (Panelist R).

The creative school culture was also characterised as having a “philosophy beyond the content” (Panelist V), which refers to a concept that emerged frequently in the study. It implies a “a lesser priority on scores” (Panelist T) and an attitude of “avoiding any progress metaphors” (Panelist G), which means trying to steer away from neoliberal views of progress and improvement as part of school reform (see Section 2.3). More specifically, a philosophy beyond the content means “modelling and encouraging thinking about student learning that is not preoccupied with ‘delivering’ content to students or ensuring that students engage with a narrow curriculum to ensure that they pass government-mandated tests” (Panelist O) but rather supports the aspects and ways of teaching that develop in students a broader set of skills. For example, there may be a learning activity that a teacher believes will engage students in developing “real-world skills” but “may not fit neatly into a curriculum area” (Panelist J). The panelists agreed that these aspects to a creative culture can also support another innovation-fostering element, namely, teacher autonomy characterised by “professional trust” (Panelist L), and they can be encouraged by “support mechanisms and processes from leadership, peers and community, time to explore, space to take risks, and frameworks that are not restrictive” (Panelist B). An additional factor, a culture of inquiry and exposure to education research and ideas, was described as an environment in which a “learning discourse” (Panelist X) is nurtured among teaching staff, reinforcing the ‘innovation as a learning process’ described earlier, where continuous and wide-ranging professional learning and “robust discussion and positive conflict” (Panelist H) is encouraged.

The enthusiasm of teachers for innovation was found to be a key innovation-fostering factor, along with the aptitude of teachers to be creative and innovative, which embodies such things as “an attitude that embraces change” (Panelist W) and “a desire to be inventive” and “a commitment to continual learning” (Panelist S). In alignment with this factor, the panelists noted that teacher-hiring policies that encourage recruitment of staff that suit an innovative vision assists in enabling innovation in schools. Money was seen as an innovation-fostering factor in schools, including investment by education authorities in technology, and the freedom for school leaders to use funding creatively to direct resources to enable innovation through collaboration and professional learning.

4.1.4 Summary

The expert panelists came to a consensus on 29 items and provided further rich insights via their commentary, which enabled the construction of a contemporary consensus understanding of innovation in a school context. This understanding encompasses innovation in schools, innovative teaching, innovative school leadership, as well as factors that foster and limit innovation. Importantly, it also provides a basis on which cases for the narrative inquiry were selected and analysed. Chapter 5 discusses the interpretation of the findings from this Delphi study in relation to wider STEM research and the findings from phase two, as well as implications of the research and recommendations for future research.

4.2 Narrative Case Studies

> Narrative inquiry and storytelling research...seeks to elaborate and investigate individual interpretations and worldviews of complex and human-centred events (Webster and Mertova, 2007 p89).

The purpose of phase two of the research was to "experience the experience" (Clandinin & Connelly, 2000, p. 86) of K–6 teachers and school leaders with respect to innovative approaches to STEM learning in their schools. The intent was to uncover the story of innovative approaches to K–6 STEM learning through the lived experiences of teachers and school leaders. Using criteria outlined in Section 3.4.2, I conducted interviews with both a teacher and a leader/principal in case study schools in each of Ireland, Australia, and the US. The case study schools were selected using criteria sampling (Miles & Huberman, 1994) to generate rich information about innovative approaches to K–6 STEM learning.

While the selected schools are situated in different geographies, as Western nations they are arguably broadly culturally similar. However, the schools exist within education systems with different educational traditions and policies that are interesting to consider in relation to the impact on innovation. As outlined in the methodology chapter, these differences pertain to the aspects of curriculum content and structure; systemic standardisation and control; and cultural factors relating to the level of progressiveness and tradition in teaching and learning. For instance, Irish schools have been less impacted by restrictive standards-based reform than those in some nations; however, innovative approaches are hindered by conservative traditional expectations of teachers and parents and a reliance teaching via textbooks, which constrains the ability to be flexible with the curriculum (Bird, 2017; Delahunty et al., 2021). The Australian context is progressive in terms of the endorsement of more student student-centred learning approaches; however, schools are somewhat constrained by neo-liberal reforms of standardisation. While most schools in the US are influenced by the common core and other standards, schools such as my US case study school have the freedom to teach what they choose, with pressures for standardisation arising largely from parental expectations of what learning entails.

All three case schools in phase two used an interdisciplinary model of STEM teaching and learning but in quite diverse ways. The Irish school employs an activities-based STEM classroom model, the Australian school a holistic inquiry-based project or "challenge-based" learning model, and the US school employs student-driven play-based "tinkering" pedagogy. The stories uncovered at these schools are outlined in the following three case studies: The STEM Room; Challenge-Based STEM; and Student-Led Experiential STEM. The pseudonyms of the respective interviewees are also used. Aspects identified in the Delphi study as features of innovative teaching are shown in italics.

4.2.1 The STEM Room – Antony and Frank

> The focus of narrative inquiry is not only on individuals' experience but also on the social, cultural and institutional narratives within which individuals' experiences are constituted, shaped, expressed and enacted. (Clandinin & Rosiek, 2007, pp. 12-13)

Antony used to teach at a small rural school in Ireland. The school has been known and recognised locally and internationally for its innovative integration of STEM into primary school teaching and learning. In the system in which Antony's school operates, teaching relies heavily on textbooks, and in most schools behaviour management as well as traditional classroom design make learning quite regimented. Antony was a key stakeholder in the development and resourcing of a dedicated space within the school where students can meaningfully engage in STEM learning by experimenting with technology and equipment, participating in self-directed activities, and attending special lessons delivered by guest teachers and industry professionals. The STEM Room was constructed in 2016 in a previous attic space in the school, and it includes 14 activity stations, electronics equipment, robotics equipment, drones, a makerspace (see 2.3.1), a green screen for film activities. There was an additional specific space for explicit lessons where laptops and iPads also feature. The innovativeness of this approach to teaching STEM was clear to Antony and his colleagues: "No-one was doing it," he said. When reflecting on why this was the case, Antony offered the insight, "Because schools are so institutionalised."

In fact, Antony credits taking some time away from teaching in this environment for a career break after teaching for 21 years as a motivator in his involvement in the eventual building of the STEM space. "I suppose it started because I went out of teaching for a while and then came back into teaching," he recalled. "When I came back into teaching, I could see just how detached what some of the things they were learning in the classroom was to what actually happens outside school." Antony, a parent himself, was concerned about how learning in schools was far removed to what he was witnessing in the world of work, particularly the use of technology.

During his career break, Antony was working to develop a digital learning company, so not only was he engaging with and designing technology enhanced learning, he was also for the first time in his adult life using his inherent entrepreneurial skills. He said this was a significant factor in the ideation and resourcing of the STEM room; he learnt how to take an idea and to find the people to back his idea both financially and with other resources: "When I was outside of school, I figured out ways of actually getting money and getting people involved to help to 'get it done' because the system in schools, they're not set up to do that." Antony discussed this in reference to innovation-limiting factors in schools, and how aspects at school such as mandatory curriculums can inadvertently discourage teachers from using creative approaches that could benefit students: "You know, you kind of get this prescriptive curriculum and off you go and it's hard to think outside the box once you've got that in front of you."

Antony was able to secure funding to set up his digital learning "start-up," and part of this funding included a study tour in the US where he visited some "STEM camps". At these STEM camps he witnessed an approach to STEM education of K–6 students that involved them playing and experimenting rather than learning structured ways. He said: "At the time I thought, 'Geez, if I ever go back to school I want to try that out, I want to give that a go.'" What Antony did not realise was that this would be sooner than expected. The digital learning business was trumped by a competitor and Antony found himself working at his local school.

Antony attributes his career break with more than just allowing him to gain business innovation and entrepreneurial experience. His recollections demonstrate that the experiences during that break gave him a fresh perspective that allowed him to connect with one of the characteristics of innovative teaching that emerged during the Delphi study: that innovative teachers respond to student need by "reviewing and adapting teaching methodologies and resources to ensure that students are engaged and challenged in their learning". Antony's break from teaching provided the opportunity and experiences for him to redirect his moral purpose by engaging students in their learning unclouded by day-to-day teaching experiences influenced by tradition and routine.

> The biggest thing was me getting out of teaching for a while and then coming back to it ... because you sort of open your eyes a bit. When you've been teaching for so long and you're in the system for so long I think sometimes you actually kind of forget why you are there sometimes. You go through the process of teaching and not thinking about what kids really really need.

At his new school, there were several factors that enabled Antony to introduce and teach the innovative STEM program. One of them was the flexibility in the role he had been given: "It wasn't a classroom teacher's job, it was the resource learning support job, so there was flexibility there with what you could do as well which was kind of handy." Ultimately, the conditions in the school reflected many of the innovation-fostering factors outlined in the definition from phase one of this study. In particular, Antony acknowledged the leadership of the school principal – which is the number one innovation fostering factor determined from the Delphi study – as key to the establishment and successful operating of the STEM Room. Antony said of the principal, Frank, "When you look back at it, he was very instrumental for it to happen." The strong themes of trust and support as features of innovative school leadership found in phase one in the study emerged from Antony's interview when he considered the role of his principal: "That's the big thing, a lot of principals would shut you down pretty quickly.” While initially Frank was a bit hesitant about Antony’s ideas, Antony was able to convince him of the merits of the STEM program, and ultimately he trusted Antony and gave him the autonomy required to start the program unhindered.

> Initially [Frank] was sort of ‘no’ and after a few months of just playing around and I sort of got some funding in as well so I applied for a google grant to get it all started and once he saw that I was pretty serious about it and I was actually getting some money in to get it started.

Antony said that Frank became very enthusiastic about the program once it was running, taking on the role of teaching in this space himself: “He was all over it like a rash, he really enjoyed it and he got really into it.”

Frank had been leading the school for many years and was nearing retirement when the STEM Room came to fruition. Despite his extended teaching career, Frank, like Antony, credits his experiences outside his own school and education system for his interest in and support of the STEM Room. He became aware of STEM education during a visit to Australia, where his daughter was living and teaching.

> It was in 2013 that I came across the concept at my daughter’s school in Queensland. I’d never heard of STEM before and I became interested in the idea of simultaneously teaching four subjects, and also teaching independent from textbooks.

At this point in his career, Frank had become “tired of teaching from the book”. In this sense, the impetus behind the innovation at Frank’s school reflected several of the aspects identified in the Delphi study as features of innovative teaching, which can be summarised as

> trying new teaching practices (to) change what teachers and students do and learn in the classroom (led by the desire to) promote creative, critical or problem-solving thinking (among his students).

The driver was not necessarily the improving of student results in a traditional sense, but rather changing student experiences. Led by a Deweyan (1910) “felt difficulty”, Frank experienced a growing unease about the reliance of textbooks as a feature of teaching in his school system, which he felt was leading to constrained and uninspiring teaching. Frank reflected that “the most important part of the STEM concept is that we were teaching and learning without textbooks”.

Frank's exposure to STEM education practices at his daughter's primary school came at a time that he had become increasingly frustrated and concerned about the institutionalisation of texts books into the classroom practice of teachers:

> I didn't like the fact that in Ireland, a lot of the teaching was based on what the publishing companies wanted to publish. So we were teaching what the publishing companies gave to us as opposed to us taking charge.

It was Frank's observations of the student-directed activities involved in makerspace in particular that stood out in contrast to the style of teaching that had become embedded in Ireland:

> Teachers had become so dependent on books and so dependent on whiteboards that they were actually losing the gift of teaching to a class and that saddened me ... I was trying to get the teachers in my school and in my local area to see that we can close the books sometimes ... because in Ireland, there's a very unhealthy relationship between textbooks and teachers; teachers follow textbooks from page one to page 100 because they feel that parents expect them to go from page one to page 100 ... It was to get away from teaching to the book.

Frank's commitment and approach to introducing STEM learning in his school when this was not a usual practice demonstrates his innovative leadership, in that he had a vision for improvement, and he applied a creative mindset to address a problem. At the beginning he had only one activity in mind, makerspace, and "had no template ... there was nothing to go by". With Antony's help, Frank, experimented with different activities, structures and routines that would work for their students. Frank personally took on the role of leading the teaching in the school, and his commitment to continual improvement was evident: "On any given day I'd be up there for five hours. I'd be teaching for three hours and the other two hours I was doing research."

Introducing this innovative approach to STEM education also meant *pushing boundaries* and *moving away from norm and convention*, which caused some rumblings in his education system. Frank had several visits from government education department inspectors to in relation to the learning in the STEM Room.

> Because the Department saw on Twitter what I was doing and because it didn't tick a box with the Department they were quite amused by the whole thing. Having said that, any inspector that came down to see it thought it was fantastic

> … but they kept asking, “Where does this fit into your timetable?” [or] “Is this maths?”... It is the timetable, because it encompasses four or five different subjects at one time and… how will I say this… they didn’t really understand what I was doing but they liked it.

His bravery in taking the risk to do things differently was, as Frank described it, predominantly due to the stage he was in his career: “I suppose that as I was coming to retirement, I felt more confident that I would be doing this despite the Department’s opinion of it.” Frank’s experience and confidence allowed him to navigate one of the noted innovation-limiting factors in schools, specifically systems of accountability, such as school inspections. As with many innovative school leaders who *can overcome barriers from system requirements*, Frank knew how to massage these pressures without inhibiting the “collaborative and often student-led” STEM learning.

> The Department could see that it was involving maths, it was involving science, that I could put it into a timetable. Once it was timetabled, they were happy. But they were a bit confused that there were no books … Departments like to tick boxes.

The STEM program was highly successful and became a model that many other schools now use. The school would receive visits from other teachers and education personnel from around the country and internationally, and the program was frequently showcased at universities. However, both Frank and Antony have moved on from that school, with Frank retiring and Antony now working in the education system in an advisory capacity in STEM education. Antony indicated that the program is no longer running in the school the way that it had when they were there. He had thought about why the program’s success has not been maintained in his absence and concluded that it was because the other teachers weren’t invested in it: “It didn’t become a whole school thing.” Frank also reflected on this, stating that over and above the systemic challenges, “My biggest problem was convincing my teachers to come on board.” Although Antony had attempted to put measures in place to ensure all the teachers in the school were involved, such as timetabling in the space, with some team teaching to offer professional learning and build shared capacity, the STEM learning largely remained the responsibility of either himself or Frank. He said that this may have dampened enthusiasm among the other teachers: “They didn’t want to know about it after a while because they weren’t part of it.”

This has made Antony reflect about whether the technology and materials should have been used in the classrooms rather than in a dedicated space, so that the teachers would have had more ready access to them and become used to using them as an embedded part of their classroom practices. Frank had the same sentiments:

> It shouldn't be a STEM Room … All classrooms should be STEM rooms. If I was back teaching a class again … I would do my research and I'd pick maybe four STEM activities … and I'd have four areas in my classroom where I'd have STEM activities on the go constantly.

Antony also acknowledged that there are cultural elements that impacted on the attitude and approach of some of the teachers to STEM classrooms, both in terms of the conservatism, religious backgrounds, and cultural aspects reflected in the selection of teachers. In Ireland, only the highest achieving students are eligible to become teachers: "They're bright, but they're very sort of controlled … they really fit into this nice tidy box." Antony discussed the notion that these factors make teachers less likely to veer from or stretch the boundaries of curriculum or move away from tried and tested teaching practices that they are familiar with.

4.3.2. Challenge-Based STEM – William and Bella

> Narrative research serves to enter previously excluded voices into the broader public forum. Such research introduces novel and sometimes critical interpretations of life by people in diverse situations whose experiences are considered mainstream or ideal. (Daiute, 2013, p. 10)

William is a principal of a small government school in Australia. The school is known as a leader in primary STEM teaching, not only because of its own STEM program, but for the role it plays as a "lighthouse" school in mentoring and sharing innovative STEM practice with other schools. The school uses the interdisciplinary or integrated curriculum approach to STEM learning, where the teaching is designed around student projects intended to investigate significant real-world problems that bring together the STEM subjects. The thinking behind this approach is that the teaching and learning programs develop students' foundational knowledge and skills in STEM related subjects, as well as skills of collaboration, critical and creative thinking, and problem solving. That is, the project-based STEM learning allows students to apply and synthesise learning from multiple STEM disciplines in ways that are meaningful to them, thus enhancing the relevancy of STEM content, which is thought to elevate students' motivation and engagement in learning (Nadelson & Seifert, 2017).

One of the early STEM projects in William's school involved a unit of learning in which students investigated the idea "What is a home?" Students applied STEM concepts from the science and technology curriculum (which in this case also includes engineering principles) as well as mathematics, to design shipping container homes. In doing so, the students examined the issue of homelessness to inform their design solutions, along with the designs of different homes around the world. This meant that the learning was more expansive than just the STEM disciplines; it encompassed a real-world problem that also linked with learning from geography and social science to complement and enhance a synthesis of learning from the STEM subjects. Several years on, William reflected on this early project in his interview: "I felt that it came out a bit half-baked, and I wasn't over the moon with it." He said that over time the projects have become more sophisticated and led to better quality learning opportunities. For example, a recent project was centred around the concept of "perspective," and students were guided through an examination of STEM from an Australian Aboriginal perspective:

> So we looked at Aboriginal technology, we looked at space and science through the eyes of Aboriginal communities ... so that meant sustainability of land practice using stars, looking at different star formations in aboriginal culture rather than Western culture.

The inclusion of STEM learning as a key focus in the school was the result of William's vision for leadership when he began his principalship of the school five and a half years earlier. It has formed part of an approach he initiated which aimed to encourage students to think about the "big picture" with work that exposes them to broad perspectives and requires them to initiate ideas and solutions in order to nurture creativity and innovation. This approach is aligned with the findings from the Delphi study, in which an understanding of innovation emerged as a process of *doing new things* used by educators to pursue a vision, and in this case also echoes the idea that the *innovation process in schools is a learning process itself*.

Even though William has been held up by his own employer as an innovator in the primary STEM education space, and leading networks of professional learning across his jurisdiction showcase his work, William is quite critical of his initial approach, which he says involved trial and error: “It's been a bumpy journey. Now I know what I'm doing, I’ve got a really good team at the moment and they’re very happy, the community are really happy … I couldn’t have said that three years ago.” William has shown this aptitude for reflection and continual learning throughout his adult life. He began teaching in his 30s after studying teaching as a mature-aged student, having initially studied architectural design and then strategic marketing. Before teaching he worked in retail and administration, and he recognises that his previous studies and experiences have informed his approach to teaching and leadership.

From the outset, William’s idea of how to lead the teaching and learning in the school was unapologetically different from what the school community had been used to. When he began at the school he was encouraged by his supervisor to re-write the school plan that existed prior to his arrival.

> I came in and we reviewed where we were and what we needed to focus on, and we decided at that point that STEM and project-based learning was going to be the focus for us, and how we could integrate learning better across key learning areas.

However, William’s open “think differently” approach met some resistance from his school community: “We had some fairly diehard parents who were quite set in doing it another way.” William reflected on this: “I can see their point actually now, when I look back on it.” The parents were concerned that the project-based STEM teaching would not meet the needs of all learners in the school, particularly the more capable students who might not be academically extended in the ways they had been before: “It was around the gifted and talented aspect.” He conceded that with the way things were operating, in terms of the planning processes and the staff capability, the school probably was not doing as well in that regard as it could have done:

> We weren’t catering well enough for the kids at the top. The last two-and-a-half years I’d say we’ve done a really great job on it. That’s with my change of staff and having the ability to actually do that. So, the idea was right, but the delivery was not.

It is not just William's ability to address the problem that has ensured that his parent community is now happy with the STEM learning in the school, the community has also changed. With new cohorts of students entering the school over the years, their parents have been aware of the STEM learning approach from the time their children enrol. William said, "We've had a complete shift in community. Now we have parents who come into the school knowing what we are and how we do things. And they are drawn to the school because of that." In fact, there is a greater demand for families seeking to send their children to the school: "We are knocking back out-of-area enrolments. People want to send their kids here."

It was this lack of teacher knowledge and expertise that William saw as a key factor in what he considers a poor start to the program. He wanted STEM to be a major focus in the school, but STEM as an integrated disciplinary notion was foreign to the teachers: "No one had even heard of STEM." Therefore, William's vision for an innovative STEM program in his school was at first unrealised because he did not have staff who shared his vision or enthusiasm to adapt their teaching for this interdisciplinary STEM model: "With that staff that I had, I did not have the ability or knowledge to deliver what I wanted to achieve." As William sees it, part of this difficulty was caused by the fact that it is a smaller school, without a large staff base to support each other with the change and the demands of the integrated STEM approach, which involves taking the time and having the ingenuity and motivation to meld together different aspects of the curriculum to meet a particular theme, rather than teaching these in discrete subjects:

> It's particularly hard because they don't have the team around them … planning becomes very tricky when they don't have the team around them. It's a whole different thing because we don't have the people to lean on and it should be a collaborative process.

Indeed, William's approach to STEM involved planning in an organic way and removing what is considered the blueprint of teaching and learning in the jurisdiction his school operates in, which is the "scope-and-sequence" concept of classroom learning. Scopes and sequences are usually designed at the start of a year, or they may have been in place for many years, and they summarise what is to be taught, the sequence in which it will be taught, and the mandated syllabus outcomes that will be addressed in the intended learning. A school would usually have in place a scope and sequence for Mathematics, a different scope and sequence for Science and Technology, and so on.

Within the different curriculum areas, topics are formed into different learning outcomes. For example, in the Science and Technology syllabus, learning about the "Living World" is distinct from learning about the "Physical World", which in turn is distinct from learning about "Digital Technologies". "There was a moving away from a scope and sequence, and that has probably been the controversial bit." William maintains that there is a need to be flexible with the programming of teaching and learning, and that the constrained nature of the traditional scopes and sequences does not allow for invented and reinvented combinations of learning. However, he admits that the more free-form, project-based approach that he first implemented did not pay careful attention to the teaching of all aspects of the curriculum: "That's probably where we went wrong the first cycle ... we didn't balance the explicit teaching as well." William sees that this was a failure of "big picture thinking"; it did not consider some of the finer details. However, he worked to overcome this by creating a system that checks off, rather than plans ahead, the curriculum content.

> So that was our issue ... but what we do now is we plan the big picture projects and we identify the outcomes that we think we will use, with flexibility, and as we go we mark things off on our outcome chart on the wall so we can identify where the gaps are.

The teachers at the school now use assessment data to determine if there are elements of the syllabus that are not being taught adequately. The school invests in progressive achievement tests, which are school-based, standardised assessments designed to provide objective, norm-referenced tests to inform teachers about their students' skill and understanding in different learning areas. The data from the tests is used within the school and is not reported to parents, the school system, or any other authority.

> [The] test comes in as a back-up for that as well, in terms of saying OK well these are the outcomes we've done – does that match up with what data is coming through? Have we missed anything? So I can tell you by looking at the science data that we haven't covered enough of the deep science content. We have done plenty of the problem solving and design aspects, but specific content knowledge is a problem for us.

William says that he and his staff continuously learn about and find better ways to teach STEM, which now includes a lot more explicit teaching of STEM subjects to supplement and enhance the learning that occurs with the projects:

> There is now a lot more of the explicit teaching. Looking at things like in maths, using the maths diagnostic tasks from the Department. If we know we are including maths in a project we will do a pre- and post-test and explicit teaching and will find out 'OK, do they understand', and then if they do, we can then apply it in the project. We've gotten a lot, lot better at that. And now the connection between the outcome being taught and the project is much stronger because they go, 'OK, now I understand why you taught me this.'

In this sense, William displays one of the key characteristics of innovative school leaders as identified in the dephi study findings from this project, which is to *push boundaries and move away from norm and convention, finding ways to overcome barriers from system requirements*. The scopes and sequences are an external requirement as set out by the teaching authority that oversees the system, and William said he felt from the outset that he could overcome this hurdle and find a way to make his innovation work. Similarly, while William and his teachers use school-based assessment data to inform their work in an environment of increasing focus on student results in literacy and numeracy, he doesn't allow pressure from government-mandated assessment scores to limit creative approaches to STEM. In terms of being held to account for student performance in these tests, William has a pragmatic view:

> When you have a small cohort sitting the tests, your data goes wildly up and down … currently our results have us as the top performers in our region. … The thing is, that can be one year, and I can be second [from the] bottom the following year. I don't feel pressured.

William said that the affluence in his community, and the educational advantage that students bring with them to school, allows more freedom for his teachers to experiment with their pedagogy:

> I mean if I was in a disadvantaged school the flexibility I would have would be so limited compared to what we've got. But our reading data is through the roof. It always has been. That helps the comprehension which means the more complex issues and ideas get understood easier.

William focuses on what he believes he and his teachers can have a significant impact on, which comes from what his student survey data is telling him:

> We've actually met our wellbeing target. We are meeting the "high skills high challenge" target. We are 10 per cent above state average and it's increasing. So what we are seeing is that our kids are feeling challenged, the kids are feeling that they've got a lot of skills, and there are fewer kids at the bottom end saying that 'Oh I'm cruising', which would be a problem.

William's leadership of STEM teaching and learning demonstrates innovation as *a drive to be creative*, as described in the Delphi study findings. Rather than as a method to create value or solve a problem, William's innovation appears to be driven by an instinctive response to do something new – a concept that is expanded on in the discussion chapter of this thesis. He models the notion uncovered in the Delphi study, that *innovative school leaders often see mistakes as learning opportunities*, reinforcing the idea that innovation in schools can be viewed as a learning process. William reflects openly on his errors, and how the program in his school is constantly evolving and improving. From the design and execution of the projects to school planning, William applies a critical view while aspiring for continuous improvement: "I had never done a school plan before I was better at it the second time around. I have developed a narrative, with the evolution of STEM as a focus too."

Over time, William's approach to STEM has matured from project-based learning to what he calls "challenge-based learning, … which is a variation or tweaking of [project-based learning]. That's been our journey." William also said that one of the critical aspects of his learning and improvement in leading STEM has been in building staff who are capable of innovation in their teaching: "At the beginning, I didn't have the staff capacity to do that in the way that I wanted it." He has addressed this through extensive professional development for his staff, and also by building his own capacity to make bold decisions around staffing. William said that it took him some time to understand that he needed to prioritise the success of the program when it came to retaining staff in the school: "At first I wasn't confident enough to make the big changes I needed to make. It wasn't until the end of that year that I went, 'No, that's enough.'" At that point, William decided to appoint temporary staff for the following year with criteria based on their capability for innovatively teaching the STEM program. This led to the appointment of a permanent staff member, Bella.

Bella has an education perspective that is aligned to William's: "I was always interested in this kind of teaching. With my teaching, I'm kind of a bit 'out there' in terms of giving things a go. More than the other teachers I have worked with." Bella has embraced the challenge-based STEM learning model, which in her classroom is always focused on addressing an essential real-world problem. Working without a scope and sequence is not a problem for Bella, who usually plans for the week ahead: "I let the student interest and community context guide me in where I take the learning … we adapt and change." For Bella, working with an innovative school leader has been a valuable step in her teaching career:

> I taught previously in a very large, very regimented school, which it probably needed to be, where there were lots of classes … I felt very disheartened for the first two years of my teaching career. I thought, this isn't what I thought teaching would be about.

In Bella's previous school there was less professional trust, and teaching practices were expected to be consistent or uniform across classes. Adaptation and experimentation in teaching practice was not encouraged: "The approach at the school didn't align with my personal views." Bella subsequently took some time away from teaching.

> I went and did a play therapy course and I worked in a children's hospital. I'm very hands on, I'm very interested in how I can concurrently do personal and social development and also do academic learning ... I want to be in a situation where we are building the whole student … it's something that's really important to me.

Getting back into teaching, Bella knew that she needed to work in a school where she felt comfortable: "So I thought, Oh, OK, well if I'm going to do this I have to be somewhere where the philosophy, the vision, the freedom is where I need it to be." What is different for Bella in working at William's school is that she has been able to satisfy her desire to be creative, see her students challenged, and have some autonomy in her classroom: "I do feel like with William's leadership and freedom and trust, and his shared vision, I do have that opportunity to take risks."

Using an integrated STEM model has allowed Bella to be inventive in creating the projects for her students: “One of our things with STEM is that it is very design thinking focused.” She is satisfied that the students are engaged in STEM learning and that their knowledge is extended further than in many other school contexts. Like William, she recognises the need to improve certain aspects of the program: “It definitely could be better in terms of our process and documentation, and that is something we are openly working on.” Unlike William, though, Bella said she does feel some burden in relation to government standardised testing, although she tries not to let it impact her teaching:

> I do feel pressured … I constantly worry … I will never teach my kids for the test, but I’m teaching my kids for life beyond school in my opinion and what that looks like is not necessarily going to be noticed on a piece of paper or in terms of a number. I think the skills and the understandings to be successful in the real world is much more important to me.

William credits the appointment of Bella with helping him realise his innovative vision for STEM teaching and learning in the school. Although she works autonomously in her classroom, Bella shares her skills and passion for being creative in designing STEM learning experiences with her colleagues to assist William in growing his staff’s STEM capability. Bella, like William, extends this sharing of enthusiasm and expertise outside her school by leading a network of teachers interested in professional learning to continually strengthen their STEM teaching. Consequently, after five and a half years the STEM program at their school is still operating and evolving, and it is expanding to other schools through their efforts.

4.3.3 Student-Led Experiential STEM – Maurice and Phillipa

> Deeply imbedded in the discourse of 21st century teaching is the understanding of teachers as social innovators who develop creative pedagogies. Teachers become 21st century learners who, through their learning, model resilience, perseverance, and confidence in ambiguity, failure, and risk-taking. (Howard et al., 2018, p. 851)

Maurice is the “founder” of a school in the US that began as a STEM summer camp. A software engineer prior to working with children, Maurice had long enjoyed sharing his “tinkering” projects with his friends’ children. He also developed a fascination with the rules and barriers around safety that he witnessed these friends place on their children’s play – the “We don’t play with sticks” mentality. Working in an innovation group for a world-leading technology company, Maurice knew the future importance of STEM and innovation skills for young people. He felt passionately that with the boundaries of child safety zones widening in society, some of the valuable innovation skills developed through play such as risk-taking, exploration, and freedom of thought, were becoming endangered.

Maurice’s idea behind the summer camp was for it to act as an antidote to the idea that play only occurs in safe, structured programs, like soccer camp. He was interested in STEM, and he wanted to give children an experience that would involve them in building things in unstructured ways so that they could learn on their own. His aim was to see children take risks, use materials and tools considered in contemporary society “not for play” or dangerous, and learn by failing. That is, he wanted to see children finding solutions in a practical, risk-positive sense. The result was a 6-day immersive STEM education camp with no set program, but lots of time for children to learn how to make things and develop an understanding that they can find solutions by playing, tinkering, or “fooling around”.

> I wasn’t in education at that point, I was a technologist. What I didn’t realise back then is that I was really kind of playing with the idea of something that I think in modern terms would be called guided play. I created a provocative environment … I’ve put in a seed of an idea … and everything the kids do in that environment with that idea covers some ground of what I’d hoped they would learn.

The success of the STEM camp, in terms of both patronage and student learning, led to the birth of an alternative type of school.

> I can trace the moment where the idea for a school started. It started with a conversation I had with one of my students at camp. It was this moment on a very long difficult day where she and I were making dinner for the rest of the campers … and the rest of the campers were collapsed at the dining table because they were so hungry and so tired … and we were cooking together and she was chopping some vegetables and I was cooking at the stove and she paused for a minute and I looked over, thinking maybe she had cut herself, it

> was that kind of pause, and I said "are you OK?", and she said, "Yeah … I was just thinking about how I've never worked this hard in my life and I wonder why school couldn't be more like this." I realised I had discovered this kind of perfect platform to experiment with various ideas and create experiences which achieve great learning outcomes, but also to the student felt very self-directed and intrinsically motivating.

Demonstrating the inquisitiveness, creativity and vision identified as a feature of innovative school leaders in the Delphi study, Maurice acted on this "felt difficulty" and decided to enter the field of school education to make a difference by establishing an "extraordinary school". The school was founded in a large US city in 2011 and grounded in play-based tinkering pedagogy. It refers to its model of learning, within which STEM is integral, as "disruptive". This model has been further described among various media reports as "pioneering", "one of the most innovative education experiments in the US", and "one of the most innovative schools in the world". Students at the school are not in regular age-based classes or even in classrooms, and there is no formal curriculum. Students instead learn in a group of "right-fit learners" (based broadly on age range, skill level and personality features or aptitude) entirely via projects centred on broad topics (such as "air" or "water") that involve "tinkering" by building prototypes, testing, exploring, and experimenting with their own ideas.

There are modelled group projects during an exploration phase and passion-driven projects in an expression phase. Both phases emphasise student interest and learning by doing, and they aim to develop skills such as collaboration and teamwork, communication (including students "pitching" their ideas), iteration, feedback, project management (including budgeting, timelines) and documentation, in addition to learning the content and process knowledge inherent in the topic. Projects culminate in the creation of products ranging from art objects, experiments, research assignments, or performances that are based on a facet of the topic that captured the students' intellectual interest. Some examples have included inflatable Mars habitats, a socially responsible confectionary company, nest boxes for rescue squirrels, and weather balloon missions to the stratosphere.

An aspect of the school's approach to STEM learning that Maurice considers most "disruptive" is that a student's learning or progress is not assessed in the traditional sense. Maurice did not expect this to be thought of as a particularly disruptive factor; however, it has emerged as such as measured by the level of challenge felt by his parent community. That is, while comfortable with an unconventional physical learning environment and unchallenged by the unorthodox use of learning tools and the less typical subject material, the parents tend to voice concern that there are no standardising assessments, exams, or tests. However, the learning philosophy underlying the absence of formal assessment is integral to the school's approach and indeed its raison d'être. According to Maurice's innovative education ideology, standardised exams and assessment reinforce the previously described rigid "safety-zone", "wrong-versus-right" thinking, and they do not work in the experimental, risk-positive environment needed for STEM and innovation skills to thrive:

> I think that in education, when you stop creating a risk averse environment, when you create a risk positive environment, where failure is considered as progress rather than "You've failed the test and you're a bad student" … where there isn't a test, but does the thing that you're working on work? Where the student is evaluating their own work against their own goals then they are more willing to take a risk, socially like putting a big bold idea out there or in making something new.

The absence of testing is possible because there is no formal curriculum that the school is accountable to, and Maurice understands that the flexibility this allows is one of the key enablers of the school's innovative approach. Despite being in the US, which features a strong reform and regulatory climate of standardisation and accountability, Maurice explained that the school's unstructured type of STEM learning curriculum and assessment regime can exist because "we are in one of the five states that doesn't require standardised tests". That is, Maurice's school sits within a state legislative framework that enables private schools to operate without mandated curriculum or state testing. Further, the school is free from the requirement of employing teachers with formal teaching qualifications, another aspect that Maurice identified as assisting the innovative approach:

> If we were a public school or a charter everyone would need the credentials. There is a set of laws in [this state] that is based on one of the amendments in the US constitution which is freedom of religion. And [this state] interprets that as that you are allowed to teach your children in any way that is aligned with

> your religion. If your religious beliefs dictate a form of education then you are allowed to teach that way … in [this state] that is interpreted as any belief … anyone can use that as the basis for a school. We don’t have to follow the NGSS [Next Generation Science Standards] or the common core which is math, reading and writing. We have complete freedom about what we teach.

This freedom of curriculum and choice of educational personnel allows for a creative approach to STEM and to education more generally that is reflected in the philosophy and terminology used in the school. For example, while there are a large number of teacher-credentialed employees on staff, there are in fact no “teachers”. There are instead “collaborators”, which is a name chosen to break down the hierarchy between teacher and student to empower the children to be the “authors of their own education”. With or without teaching qualifications, the collaborators are highly educated with a variety of academic and employment backgrounds such as childhood studies, film-making, design, social science, liberal studies, creative writing, history, art, social justice, urban and environmental studies, zoology, and science research. Maurice credits the flexibility to employ staff as a factor in the success of the innovative STEM learning model, with certain personal attributes or characteristics more important than formal teaching qualifications. For example, aside from being able to freely employ a collaborator who has a background relevant to STEM specific skills, if a qualified teacher possesses a deep sense of wonder about the world, this sense of curiosity can be modelled and transferred to the students.

According to Maurice, collaborator positions in the school are in high demand, largely because of the professional autonomy and opportunity for creativity that teaching in this environment provides:

> When we open up a position we usually collect 150 resumes and interview 20–30 people for the position. There are a huge number of teachers who want to create intrinsically motivated experiential learning, especially in STEM. I think for a lot of teachers the attraction is that we don’t have a rigid pedagogy as such, there is a framework and within that you can bring your practice. So if you move through the school and look at the different classrooms you see a great deal of variation in the implementation because it is not designed to be dogmatic.

Indeed, the ability to attract people with the values and skills aligned to the approach of the school is considered one of the reasons it has maintained and evolved its innovative status for more than 10 years, which according to Maurice can be a struggle: "It is very typical for progressive schools in the US to normalise over time." Indeed, Maurice is vigilant in ensuring that his school avoids moving away from its core educational values so as not to "fall down towards normalisation valley". In fact, Maurice and his executive began observing some of the more traditional classroom practices creeping into the program when COVID-19 impacted the teaching and learning and some families chose to have their students learn from home while others attended the school site:

> Many of the classrooms this year have kind of like adopted a de facto morning academic schedule and an afternoon project-based schedule … there is nothing in the framework that says you can't do that, but there is no good reason to do it that way either. … We don't want to separate the experiential from the academic, we want the academic to be in the context of the experiential. You never want a student to ask "Why am I learning this?" The reason should be embedded in the experience. But that sleepy and slippery slope … this is the first time we noticed this, and we're like, "Are we headed down this slope?"

Maurice has addressed this concern with his staff by having reflective conversations. While there is no dogmatic or authoritarian approach to how the teaching and learning occurs, ultimately the school has the freedom to hire and fire collaborators, and the staff that remain are drawn to the school because they share the innovative educational philosophy that it espouses. According to Maurice, an environment that promotes the discussion of ideas and continual reflection on the work enables the culture of innovation.

Maurice acknowledged that, despite being able to overcome this challenge without difficulty, the biggest obstacle to the school's innovative approach presented itself early on and continues as each new cohort of students enrol. It relates to the challenge experienced by parents in the absence of formal assessment, more precisely their nervousness when they witness learning that is vastly different to their own school experiences. Maurice has an analogy to describe this phenomenon; he refers to it as the "Thanksgiving slump", which is the period of dissatisfaction or questioning of the school's philosophy by parents after they are questioned by friends and family members about the alternative way their child is learning.

> Thanksgiving is a national holiday here in the US and everyone goes home for the holiday and they have these big meals, and right after Thanksgiving we would notice that parents in their community meetings, their mood and experience with the school would drop down and we noticed that it was because some of them, their adult siblings are kind of making fun of them at the Thanksgiving table for putting their kids in this crazy school where there is just people running around.

The "running around" refers to the physical environment of the school, which is as unstructured as the curriculum, without traditional classrooms and desks, and even without the spending of large amounts of time using computers and devices that is emerging in most schools.

Over the decade of developing the school, Maurice and his staff have noticed other patterns in the level of parental acceptance of and satisfaction with this STEM-centred innovative learning approach:

> Your second year at [the school] is often a tough year because the first year everything is rosy and shiny, second year often one of the parents will have a concern or anxiety that they never shared either with themselves or their spouse … By the second year, they are not seeing that test that they needed to see, or the way we approach math doesn't look like math to them or you know, "My best friend's kid just won a science fair award, how come my child didn't" … Well, we don't sign our kids up for science fairs, what we do is science fairs all the time.

Maurice has learnt to overcome this barrier by developing strong communication with parents about the learning their students are experiencing.

> It is not easy to make something that presents education in a way that is not easy to map to your own experience as a parent. So if you think back at you going to school and then your child goes to a school and halfway through the school year you think to yourself "wait, I mean I know they are a hands-on project based school, but is she ever going to take a test?"– like actually no, we have a different way of getting there. And so keeping the parents informed about what

> we're doing and learning to share their child's work in a way that alleviates their anxiety.

This level of communication has come via trial, error, and experimentation. Maurice used the example of reporting on student learning progress: "Reporting to parents has really evolved since day one." This is something he said he did not adequately consider or plan through at the outset:

> In the first year one of the parents during a parent meeting kind of cornered me, in an area that I really should have thought about more deeply before first day of school, and she was like, "I don't get it, how are you going to know if they are learning? How do you track their learning?" And I said this thing, which I stand by, but it sounds very formal to me, I said, "The manifest work product of the student should obviate the need for testing."

Over time, Maurice and his staff have developed ways to "actively collaborate with the parents, and storytell with the parents" to demonstrate student learning:

> The staff write these narrative assessments, these beautiful little essays that explain the progress they've seen and the challenges that they had at the beginning of the year that now they do those things without even thinking about it, whether that was multiplication or dealing with somebody else's idea.

However, it remains the case that Maurice and his staff have felt compelled to illustrate student learning in a way that satisfies parent's need to relate it to their own educational experiences:

> So, as the students go through life and [the school] the quality, quantity and depth of their work should increase over time and what we have done is we have sort of formalised that into rubrics because the rubrics really give the parents confidence more than the narrative assessments that our staff write … the parents pretty much just read the rubric and they try to translate it into grades.

These parents have made a choice and a financial investment in sending their children to a school that emphasises STEM learning done very differently. According to Maurice, "They have thought deep and hard about it, and they have backed it up with the money", yet they are unable to let go of some of the traditional ways of thinking about education.

Collaborator Phillipa also named this unshakeable traditional thinking about schooling and education by parents as an innovation-limiting factor, although she does not view this or anything else as a barrier or signification challenge:

> I always try to put past whatever the challenges are… but if there is a challenge it certainly would be the parents and the way that they view it. It's funny because you have the parents who say, "I want to send my child to [the school] because it's the right fit" and then then minute they're at [the school] they kind of question everything.

Like Maurice, Phillipa has not allowed parental pressure for normalisation to alter the way she teaches STEM; instead, she has developed ways of communicating with and reassuring parents that the school's approach is the right one. In particular, she draws on the parents' memories and feelings of dissatisfaction with their own schooling experiences, and she reassures them that while the learning outcome is the same or better, it is the process that is different:

> I mean for me, it has just been showing them that we are still doing it, it just looks a different, or saying, "Hey, what about school didn't work for you, and like think back… how could school have worked better?" and point out, "Oh, it looks like what we do at [the school]."

Passionate about the creative, STEM-centred, intrinsically motivating approach to STEM learning at the school, Phillipa has no concerns about assuring the parents of its merits. She ardently believes that children are instinctual learners who benefit from having agency in their learning, and she thinks of herself as a partner and co-designer in this process. Phillipa's approach reflects the teaching style that emerged in the Delphi study, wherein innovative teachers review and adapt practices and resources to ensure that students are engaged and challenged in their learning. For Phillipa, teaching is a process of fostering creativity and curiosity, for the students and herself. She said that she genuinely collaborates with the students and navigates the STEM learning according to their interests, crediting the freedom and autonomy she is afforded to be inventive, take risks, and make mistakes as allowing her to model the same learning process to her students.

It is no surprise that Phillipa views teaching as a creative, exploratory, and experimental activity, given her affinity with the design process. Phillipa spent the first 10 years of her adult working life as an interior designer and she came into teaching under an innovative teaching credential program that allowed a similar type of experiential "learning by doing" approach that is encouraged at her school:

> It was like the [the school] of teaching credential programs, where I spent 2 years co-teaching and learning while doing and all of that. I spent my 2 years at an independent school that had begun to support the Black community back in the 1970s because the schools were so bad there, so they have a really progressing social justice driven message and that was important to me.

In fact, Phillipa's teacher education program not only encouraged innovative pedagogical practices but is known for instilling in its teacher education students the skills and values to create organisational and social change, transform schools, and commit to improving futures. Upon graduating from the program, Phillipa was inspired to make a difference for disadvantaged students in the public school system, but the innovation-limiting aspects of the school she encountered deterred her.

> After I left there I did one year in our public schools here before I ended up at [the school] … and of course I wanted to support the public school community but the school just wasn't a right fit … it was a hard to staff school and when I took the job there were a number of programs that they were supposed to have in place that I was really excited about, and then that money got pulled or it got shuffled and so those programs weren't happening in that way and the administration took over with that stuff. I didn't agree with the way they went about it and so after that I ended up at [the school].

What Phillipa enjoys about her school now is the freedom for her to be creative with learners, and the freedom for her learners to also be creative. The school encourages its teachers to "say yes" to students and to let the students be hands-on and driven by their own ideas. Phillipa believes that while there is a place for referencing common core and science standards to reflect on the learning that is happening with her students, she is energised by the fact that her teaching is not restricted by the pressure of these standards governing her work. In fact, she is convinced that the students benefit from this freedom, with the STEM learning approach enabling authentic and meaningful learning and therefore deeper and longer lasting understanding.

Phillipa admitted however that the teacher-as-collaborator approach does not work for everyone. Thinking of the example of two new teachers to the school, both from similar careers prior to joining the school, Phillipa reflected on the suitability of one of the teachers to the school's philosophy more than the other:

> We have two new staff members this year, and they are both coming from a decade in public schools. One feels like he should have been in [the school] forever, he did this type of learning in his public school himself, project-based, believing in the child… the other one is struggling to let go of planning down to the last minute, trusting that "I'm touching all of these things" … and I think I'm more like the first one … [the school] just feels like home to me.

Despite this, Phillipa asserted that there is no need for teachers to have a certain formula to operate successfully at the school: "We are all very different in our teaching styles and how we go about things." That is, while the school is not the right teaching environment for everyone, she values the diversity that exists among the teaching staff as a positive, innovation-fostering aspect of the school.

Both Maurice and Phillipa described the unique approach to STEM teaching and learning in the school as an "exploration" and a "co-creation". Maurice identified that founding and developing the school has been both an innovation and an education. He explained that the teaching methodology employed in the school remains open to interpretation and adaptation by the individual educator. However, there exists among the collaborators as a group a set of insights and practices that has developed through the "educational experiments" of both the STEM camp and the school. The edict that Maurice reinforces with his educators, families, students and even educationalists beyond his school is that the STEM learning in his school has developed via the learning that has emerged jointly with the collaborators and students by their "exploring, innovating, and reflecting" throughout the decade-long life of the school. In this sense, authentic engagement in STEM learning has resulted in learning for both the students and the educators.

4.4 Conclusion

This chapter has reported the findings of the study through the stories of the expert panelists, and the educators in three case study schools. The next chapter discusses insights about innovation in schools and factors influencing innovative K–6 STEM learning that have arisen at the intersection of commonplaces (Connelly & Clandinin, 2006) from both phases of the study.

Chapter 5:

Discussion

> It is also possible to frame the innovation process as one of story-telling and re-telling. Consider the classic myth or fairy tale. It begins (once upon a time) with a call to adventure after which a great journey begins. After a daring exploit or challenge, there is resolution and the moral of the story is delivered. Our innovation process has a similar story line. (Beckman & Barry, 2007 pp. 45-46).

The previous chapter outlined the findings of the two phases of the research. As described in the methodology chapter, the overarching research approach applied in the study is that of narrative inquiry, with phase one adopting the Delphi method and phase two explicitly using narrative inquiry. This study has used a story-telling process in uncovering innovation in schools and factors that influence innovation in K–6 STEM learning. This chapter is a *restorying* of the findings to describe insights about school innovation and innovative K–6 STEM education in relation to the research questions and the literature.

To briefly review, a Delphi study was carried out in the initial phase of the research to extrapolate a comprehensive definition of school innovation, elicited via the perceptions of experts in the field. Phase two involved investigating examples of K–6 STEM learning innovation in schools in Ireland, Australia and the US, uncovering stories through the lived experiences of teachers and school leaders in schools influenced by different educational traditions and policies. The findings presented in the previous chapter were extrapolated from 25 participants in a Delphi study and from the stories of six characters located across three case study schools.

The following sections retell and restorify the findings in relation to the research questions, highlighting the insights that have emerged at the intersection of commonplaces (Connelly & Clandinin, 2006). That is, the discussion synthesises the insights emerging from both phases of the study in light of temporality (the past and present of the individuals, contemporary policy and economic influences and conditions), sociality (social and existential conditions), and place (factors relating to the location of the schools) to address the research questions. The findings are therefore discussed as a complete story, with an analysis of findings from phase one (Delphi) about innovation in schools combined and discussed alongside the findings from phase two (narrative case studies) to address each of the three research questions:

1. How is school innovation defined by experts in the field?
2. What are the factors that foster and limit innovation in schools?
3. What factors enhance or prevent innovation in K–6 STEM learning?

5.1 Innovation in Schools

The aim of the first research question was to uncover a broad and contemporary understanding of innovation specific to schools that works beyond the implementation of technology enhanced learning and applies to the current socio-political context. The definition was produced via a Delphi study, and in the wider context of the research has served to establish a criteria in which to examine both STEM innovation and innovation in schools more broadly. The modified Delphi study was informed by existing literature and designed to provide new insights which are discussed in the following section.
As outlined in the previous chapter, a panel of 25 experts participated in a Delphi study to produce a consensus understanding of innovation in a school context:

> Innovation in schools is a process and an outcome. It is predominantly a process or response used by educators in the face of challenges or changes or to pursue a vision. Educators are charged with creating an innovative future workforce and therefore innovative teaching in schools is multilayered. It involves applying innovation to teaching (the process) and is also the practice of teaching to build innovation skills in students (the outcome).

The insights uncovered in this study about innovation in schools can be explained in relation to innovation as a process and an outcome. In addition, a broad and contemporary definition of innovative teaching is discussed, which includes a model of school leadership, that was applied in examining the STEM case study experiences.

5.1.1 Innovation in Schools as a Process

Innovation has long and widely been named as a process in business and organisations (Beckman & Barry, 2007, Crossan & Apaydin, 2010; Salerno et al. 2015; Kahn, 2018; Utterback, 1971) and in schools (Ferrari et al. 2009; Giles & Hargreaves, 2006; Hargreaves, 1999; Seryukov (2017); Tytler et al., 2011), and this study confirmed this, with the first part of the Delphi study definition outlining that innovation is a process used by educators (which includes both teachers and school leaders) in response to challenges or changes or to pursue a vision. Two features arose from the study in relation to the innovation process in schools; innovation as a learning process and innovation as a creative process.

5.1.1.1 Innovation as a Learning Process in Schools. The study found that educators often think of innovation as a learning process in terms of their own professional learning. The notion of innovation as a learning process is a concept applied in workplace learning but has yet to be studied widely in a school context. According to Delphi respondents, when it comes to innovation in schools the learning garnered by educators from the process of creatively designing new learning experiences or morphing ideas into something contemporary, interesting or effective in the administration of a school is as valuable as the outcome of the innovation implemented. That is, the experts consider innovation to be a process of problem-solving, inquiry and ongoing design, which reinforces Beckman and Barry's (2007) model of innovation as a learning process within organisations (not specifically schools) that is a merging of experiential learning theories and design thinking.

The experimentation and iteration described in the schools involved in phase two of the study fits within Beckman and Barry's model, as well as the learning from experience, mistakes and reflection which is part of Høyrup's (2010) employee-driven model of innovation as a mode of learning in a workplace. Frank and Antony took their observations and experiences from both inside and outside of their schools, more specifically Antony in the STEM camps in the US and Frank in the makerspace in schools in Australia, and reframed these when using a design process to build their own STEM learning template. They experimented with different activities, sought input from industry and education experts and trialed structures and routines that would work for the students. The innovation and learning process not only applied to the curriculum and lesson design, but included timetabling, teacher allocation, professional learning activities, mechanisms to meet system curriculum requirements and resourcing for the STEM programs. This design process continued throughout the life of the STEM program, with research forming a large part of the teaching allocation for the STEM room. For example, for at least two hours each day, Frank and Antony would spend time reading, networking, sourcing, and experimenting with new activities that could be used in the STEM room, evaluating and refining the program as they gained more knowledge. Even after the conclusion of the program, the teacher Antony continued to reflect on how it could be improved, and how his learning from this project would impact the implementation of other projects and in other schools.

Comparably, William described the process of designing and implementing STEM integration in his school, including curriculum design, system curriculum and planning requirements and staffing, as involving a significant amount of trial and error, reflecting openly on his missteps and how the program continued to develop and improve. William also frequently engaged experts within and outside the education field, including in design, computer science and management consultancy, as part of the innovation process in designing STEM learning. His learning not only applied to the activities in the classroom, but also in the scalability of his program beyond his school, and aspects of how he leads others in STEM education. A key aspect of William's story is the way he thought critically about the design and execution of the STEM projects and made revisions and adjustments with each iteration. For Bella, the learning that she undertook by being creative and inventive in designing and implementing STEM learning was an important aspect of her job satisfaction. She described the design thinking that was key to her learning as a teacher as well as the students' learning in STEM, as the innovative program evolved.

Maurice referred to the foundation and development of his school in terms of both an innovation and an education. That is, the pedagogical insights and STEM learning practices that exist in the school have evolved via "educational experiments." What is more, Maurice identified that a STEM learning model in his school developed via the learning that occurred jointly with the educators and students "exploring, innovating, and reflecting" in collaboration. In addition, Maurice's experiences highlight that the trial and error design learning process applies not only to the teaching and learning, but to wider operational aspects of the STEM program in his school such as communicating with and gaining the support and educational partnership of parents. That is, Maurice's example emphasised that the innovation learning process is relevant to management functions in schools, for both school leaders and teachers. "Observation is at the core of the innovation process" (Beckman & Barry, 2007p. 35) and Maurice, Phillipa and colleagues gained a thorough understanding of parent need by observing patterns of discomfort with disruption. In a process similar to the "innovation as learning process" that Beckman and Barry (2007) identified in organisations (not schools), Maurice, Phillipa and other staff produced a solution for a key parental need; palatable evidence (but not standardised assessment) that their children are progressing in their learning.

There is a large body of work that discusses professional learning in the context of change for educators (Darling-Hammond, 2008; Fullan, 2002; Hallinger, 2003; Resnick et al, 2010; Senge, 1990; Senge et al 2012; Silins & Mulford, 2002), but the links between professional learning, workplace learning and innovation as a learning process are limited. Bakkenes et al. (2010) uncovered the learning outcomes of teachers that were required to implement a different way of teaching and hence studied teacher learning in the context of innovation rather than as a process of innovation. Westbroek et al. (2019) found that "teachers are explicitly learners" (p50) when they work in collaborative design teams to create new curricular materials and that the collaborative design process positively affects the professional development (learning) of teachers. This study has confirmed that innovation, when viewed as a professional learning process infiltrates numerous aspects of teaching and school administration. Further, it described how the innovation learning process was used in two schools in implementing STEM education K–6.

5.1.1.2 Innovation as a Creative Process. The notion of innovation as a creative intellectual action (Montenegro, 2019) resonated strongly among the Delphi participants and appeared as a key theme in the experiences uncovered in the case study schools. The creative process was described by Delphi panel members as a response of vision-led leaders used to achieve objectives in ways not considered previously. This is in alignment with the research of Borasi and Finnigan (2010) and Yemini et al (2005), who found innovation among educators to be a personal factor or competency associated with entrepreneurism. However, the definition that emerged from the Delphi panel study described this notion as a drive to know and do things differently, and where innovation can be considered less of a personality characteristic and more of a basic ideal underlying the approach that a teacher or school leader applies to the everyday and or longer-term aspects of their role.

This was also a finding of Tonkin's (2016) research, in that creative school leadership is about "seeing, thinking and doing things differently" (p.42). However, in Tonkin's work, the "think differently" approach was associated within the framework of "success," high performance and sustained improvement, including "improving the life chances" of students. This could be compared to Fullan's (2002) research which outlines the idea of moral purpose in driving educational change. However, while often motivated by the pursuit of a vision, the process of innovation as an act of creativity uncovered in the Delphi study is not automatically associated with improved student academic results in a traditional sense, nor as part of systemic education reform.

In fact, Delphi respondents commented that when viewed as a creative process, innovation should be considered outside the moral or ethical ideals that are usually implicit in educational actions, and in particular where improvement linked to student results in standardised tests. Simply, it was described by the panel as a tendency or approach to teaching or leadership that involves morphing ideas into something contemporary, interesting or effective in the administration of schools or in the classroom. Further, innovation is not always associated with intentional strategic decision-making and can be used by educators at different times for different reasons.

This creative process of innovation was apparent in the case study schools. In introducing the STEM room, Antony was driven to experiment with ideas that he had seen in the US at STEM camps and implement some approaches to learning that very different to what was happening in other schools in his education system. At the heart of his vision was the understanding that the real world required knowledge and skills that were different to those reinforced in the traditional style of learning in his school, but the driving force was the desire to "give that a go" and pioneer an interesting and engaging STEM learning environment. For the principal of the school Frank, the driver for the STEM room was not necessarily improved student academic results, but rather changed student experiences via different teaching practices. That is, Frank was led by a Deweyan (1910) "felt difficulty" he was experiencing, with a growing unease about the reliance of textbooks as a feature of teaching in his school system. For Frank, "the most important part of the STEM concept is that we were teaching and learning without textbooks." It was a philosophical opposition to traditional ways of teaching, and a desire to do things in a different way.

Similarly, William was driven by creativity and applied a think differently approach to the leadership of his school, determined to "re-write the plan" to include STEM learning in a way that was unapologetically different to how learning had been occurring in the school prior to his principalship. In his pursuit of innovative learning experiences, William did not allow pressure from government mandated assessment to limit the creative approach to STEM teaching. As the program progressed and he found the need to establish ways to comply with system planning and programming requirements, and despite seeing some risks, William chose to apply an innovative approach to this as well. Bella, the teacher at the school, was also attracted to taking risks in order to do things differently. In fact, she was driven to be involved in his school because, unlike in her previous school, she found it to be an environment in which she felt the freedom to have some autonomy and apply creativity to her teaching.

Maurice and Phillipa clearly derive job satisfaction from the creativity afforded them in their innovative school environment. Phillipa described teaching as a creative, exploratory and experimental activity, and acknowledged that the freedom to be creative with her learners is a feature of school innovation that is not available in many settings. Maurice had a vision for a different type of learning experience, creating every aspect of a school and STEM learning program without regard for and indeed with the aim of disrupting conventional notions of learning and traditional forms of academic achievement. Both Maurice and Phillipa model creativity as innovation to the learners in their school, simulatenously being creative and innovative while encouraging their STEM learners to be creative and innovative while demonstrating through their leadership, teaching and learning that they are "willing to take a risk," put "a big bold idea out there" and make "something new."

Some studies define innovation in education as being linked with improvement (Seryukov, 2017; Tytler et al., 2011). However, the OECD acknowledged the contention around linking the notion of "improvement" in many public services, including education, to innovation (OECD, 2016a). Both phases of this study uncovered that, while not always the case, innovation can be viewed simply as a creative intellectual pursuit by educators in schools.

5.1.2 Innovation in Schools as an Outcome

Some previous studies defined innovation in schools as a process (Seryukov, 2017; Tytler et al., 2011) whereas other studies determined innovation in schools is both a process and an outcome (Ferrari et al. 2009; Hargeaves, 1999; Jeffrey, 2006; Kozma & Anderson, 2002; Langworthy et al. 2011; Mirzajani et al., 2016; Moyle, 2010), and therefore it was important to make this distinction as part of this study. Delphi respondents agreed with the scholars that determined modern education should be shaped by innovations and should also train students to produce innovations (Mirzajani et al., 2016) and that innovation is an outcome of innovative teaching, in that it involves changed teaching practices that build "creative agency" (Jeffrey, 2006) leading to creative student learning that promotes the skills that students need to live and work in the 21st Century. Specifically, Delphi experts agreed that innovative teaching in schools is multilayered, involving both applying innovation to teaching (the process) as well as the practice of teaching to build innovation skills in students (the outcome). This definition applied in the study of the STEM schools, where it was apparent that providing experiences to build innovation skills was one of the driving factors for the educators in the implementation of the STEM programs.

As Antony described, using an innovative lens in his thinking allowed him to contemplate the skill development that he felt students needed and that were not necessarily nurtured using the teaching methods typically employed in his setting. Frank was determined to promote creative and critical thinking in his students by instituting hands-on STEM activities and ending the reliance on teaching by text. William's approach to integrated STEM learning in his school was aimed at encouraging students to think about the "big picture" to inspire creativity and innovation. Bella's passion for building the whole student by concurrently considering the personal and social as well as academic development of students in learning tasks drove her innovative teaching in STEM. Maurice has been driven to expose students to learning that breaks the risk-averse societal norms hindering their natural creative development, instead supporting the growth of skills compatible to the innovation and tech-rich economy he was formerly part of himself. The play-based tinkering pedagogy that engages students in STEM learning at his school via inquiry, design, prototyping, building and finding solutions in a practical, risk-positive sense aims to nurture innovation-relevant skills such as collaboration, teamwork, communication, iteration, feedback and project management. Phillipa describes the importance of agency and creativity for the learners in equal measure to the importance of these factors for her as a teacher, emphasising the central role that the development of these skills in students play in the innovative STEM learning in her school.

This definition, where innovation involves applying innovation to teaching as well as building innovation skills in students is useful for educators to consider when designing STEM learning and when considering the rationale for experimenting with innovative approaches; the innovation process not only assist teacher's learning but also produces rich learning opportunities for their students.

5.1.3 Innovative Teaching

As outlined in Section 4.1.2, the Delphi panel study found that innovative teaching involves trying new teaching practices that change what students do and learn in the classroom, which confirm the findings of Kozma and Anderson (2002) and Langworthy et al. (2010). In contrast to studies that tend to attach the definition of innovative teaching to specific practices (Heaysman & Tubin; 2019; Kozma and Anderson, 2002; Langworthy et al. 2010; Ross et al. 2001; Voskamp et al. 2020; Zhu et al. 2013), this study provides a broad understanding that can be applied across practices. Drawing on themes in relation to disruptive innovation theory (Christensen 2008, 2014; Christensen et al, 2013), and more aptly Law's (2008) notion of sustaining or subversive innovation, the new practices can be emerging, including but not limited to trying new technology enhanced learning approaches. They can also build on positive and effective existing practices, draw from historic thinking. and can involve engaging with education research. Design thinking has been named as a pedagogical approach (Carroll, 2010; Koh et al. 2015; Norman, 2001; Scheer et al, 2012), and as outlined earlier in the chapter, has been linked to innovation as a learning process in schools. This study further links design to innovative teaching, in that the Delphi panel found that it can involve using a problem-solving or design approach to promote creative, critical or problem-solving thinking.

This definition of innovative teaching was applied when selecting the STEM case study schools, and its features emerged from the experiences described by the educators involved. In all schools, the innovative approach to STEM involved new teaching practices that changed what students did and learnt in the classroom. The STEM room was a unique offering in Frank and Antony's school system, and was generated from a melding of ideas between the two educators; Frank spurred on by the makerspace he saw in his daughter's school in Australia and Antony by the STEM camps he attended in the US. William's integrated project-based learning program was held up as a model of innovative practice for others in his school system, and was completely new to his students, teachers and school community. The STEM learning model in Maurice's school has been described by media as "pioneering," "one of the most innovative education experiments in the US," and "one of the most innovative schools in the world." There are various innovative elements in the school including the tinkering pedagogy, the curriculum, the philosophy and staffing, the organisational and physical environment and the approach to monitoring learning progress. The innovative approaches in all three schools evolved and changed over time as the educators undertook *innovation as a learning process* to refine and learn as the programs developed. In addition, aligned with the feature outlined in the definition, all innovative STEM approaches evident in the cases promoted the use of creative, critical or problem-solving thinking in student learning.

5.1.4 Innovative School Leadership

Innovative school leadership has previously been studied in relation to specific characteristics and behaviours of leaders such as work engagement (Koch et al, 2015) trust (Lawson et al. 2017; Schwabsky et al., 2019), entrepreneurial behaviours and practices (Borasai & Finnigan, 2010; Park, 2012; Pihie et al. 2012; Wibowo and Saptono, 2018; Yemini et al. 2015) or in relation to features of shared vision and democratic leadership practices (Buske, 2018; Riveras-León and Tomàs-Folch,2020; Vaara & Lonka, 2014), all of which are replicated in this study. Innovative school leadership is however largely discussed in literature in terms of transformational leadership practices in relation to school reform which often involves the leadership of large scale "top down" innovations and frequently measured as successful by improved student performance in standardised tests (Fullan, 2011; Geijsel et al. 2001; Hopkins et al. 2014; Lawson et al 2017; Levin, 2012). Conversely, the Delphi panel study produced a comprehensive definition of the features of innovative school leaders, in relation to their innovative behaviour or their innovation supporting behaviour, without attachment to neoliberal reform ideas of "success".

As outlined in Section 4.1.2.3, the study found that innovative school leaders exhibit professional and relational *trust* in teachers, and encourage *experimentation* and adaptation in teaching practices, shaping a culture where mistakes are learning opportunities. Innovative school leaders are driven by an *aim* or vision, whether that be for improvement, to achieve a particular objective or to "think differently" as a feature of an innovation as a creative process. Innovative leaders apply a creative *mindset*, often pushing boundaries and moving away from norm and convention. A key feature demonstrated by innovative school leaders is that they can find *solutions* to overcome barriers from system requirements presented by such things as mandated curriculum, standardised assessment and funding restrictions

These dimensions of innovative leadership can be summarised as trust, experimentation, aim, mindset and solutions (TEAMS), all of which were exhibited by the leaders in the STEM case study schools. The TEAMS acronym is meaningful in that the STEM school participant leaders worked in partnership with their teachers to achieve the innovation in their schools. This is interesting when considered alongside research by Thurlings et a. (2014) and Russell and Schneiderheinze (2015) who found that collaboration between teachers is not necessarily a factor in innovative school cultures (see 2.1.6). As was highlighted in the K–6 STEM case studies, trust and a shared innovative mindset, rather than collaboration, are important aspects of the team relationship for the success of innovative STEM learning. This will be illustrated, along with a depiction of how leadership fostered innovative teaching of STEM, in the following section.

5.2 Factors That Affect Innovation in Schools

This section discusses the factors that affect innovation in schools. It applies the findings from the Delphi study and the narrative that addressed the research question *What are the factors that foster and limit innovation in schools?* to discuss the innovative approach to teaching and leadership of STEM learning in the three case study schools.

5.2.1 Innovation-Fostering Factors

The Delphi study found a number of factors that were considered important in fostering innovation in schools which were confirmed as significant in the three STEM case study schools. These can be categorised as relating to leadership and culture as well as aptitude and enthusiasm of teachers. In addition, the study uncovered that educator work experience outside of school can also be a factor that fosters innovation in innovative STEM teaching and leadership.

5.2.1.1 Leadership and Culture. The four innovation-fostering factors related to leadership and school culture uncovered by the study are:

1. Innovative leadership by the principal
2. A culture of creativity and risk taking within the school;
3. Teacher autonomy; and
4. A culture of professional inquiry and exposure to education research and ideas.

The Delphi study found that innovation is fostered in schools when innovative leadership is demonstrated by the school principal. This is in alignment with other studies that found innovative leadership to be important, if not essential, to innovation in schools (Buske, 2018; Moolenaar et al. 2010; Park, 2012; Pixie et al. 2012; Riveras-León and Tomàs-Folch, 2020; Vaara and Lonka, 2014; Wibowo and Saptono, 2018). The TEAMS model of innovative leadership (referred to in the previous section) is outlined in detailed further in this section.

The culture of a school is the "emotional spirit" (Dewey, 1916) that permeates its activities and as such one school can be differentiated from another by the characteristics of its culture (Kallestad, 2010). Chang et al. (2011), Paletta et al. (2021) and Balker (2015) all found that certain aspects of a school culture can promote innovation in schools. Balker in particular linked notions of support and also pressure, in terms of high expectations for teachers in focusing on their work, as linked to teacher innovative behaviour. The Delphi study found that a school culture that fosters innovation is one that embodies an open-minded management style that promotes creativity, acknowledges and rewards innovation and demonstrates an attitude of encouragement to break the rules of convention. The creative school culture was also characterised in the Delphi study as having a "philosophy beyond the content" which involves promoting thinking about student learning that is less preoccupied with student test results and is supportive of teaching in ways that develop in students' deep understandings and a broader set of skills.

The third and closely related innovation fostering factor uncovered in the Delphi study is that of autonomy, where teachers feel a sense of empowerment to design creative or innovative learning experiences. There are few studies examining teacher autonomy and innovation in schools, perhaps because of the standardising effect of education reforms have limited teacher autonomy, even in school environments intended to be innovative (Crawford, 2001; Fidan & Oztürk, 2015; Mavrogordato, 2019). This is despite the fact job autonomy has one of the strongest impacts on innovative work behaviour in industries outside of education, which could be replicated with teachers in schools (Baharuddin et al. 2019). Nevertheless, Peterson and Thomas (2020) found a link between increased teacher autonomy and innovative STEM teaching, which was confirmed in this study as characterised by "professional trust", or a trust in the professionalism of teachers. That is, innovation can be fostered when educators are trusted with the autonomy and discretion to apply their knowledge and skills in different ways as well-educated and trained professionals with subject matter and pedagogical expertise. This professional trust goes beyond the leadership of the school; it means receiving support from the education system, colleagues and the school community.

The Delphi study also found that innovation can be fostered in a school where there is culture of inquiry and exposure to education research and ideas. Moolenaar et al. (2010) found an innovative culture is nurtured when leaders share and develop the school's vision with the teachers and provide teachers with opportunities for intellectual stimulation. Both Chang et al. (2011) and Paletta et al. (2021) emphasised the importance of a "learning climate" and strong opportunities for professional development with innovation in schools. This study found that innovation is fostered where a "learning discourse" is nurtured among staff as well as continuous wide ranging professional development. The culture of inquiry is also somewhat linked to innovation as a learning process as outlined earlier in the chapter, wherein the process of innovation in schools works to promote adult learning from the actions of design, problem-solving, experience, mistakes and reflection.

The four innovation fostering factors relating to leadership and culture were clearly evident in the stories uncovered in the K–6 STEM case study schools. All school leaders, Frank, William and Maurice, exhibited a distinct and conspicuous aim or vision driving the innovative approach to STEM teaching and learning in their schools. Frank's reason to implement the STEM program at his school was in his growing unease about the institutionalisation of textbooks, and the resulting inflexibility of teaching, into the classroom practice of teachers in his school system. He wanted to change student learning experiences and to help teachers to see the value of student-led learning. William's interdisciplinary approach to STEM aimed to encourage students to think about the "big picture" to inspire creativity and innovation, however his approach was continually changing and evolving. His drive to lead was more about applying a "think differently" approach in his school, for the students in their learning but also for the teachers, the school community and himself. Maurice's vision was motivated by undoing the 'we don't play with sticks' risk-averse mentality in society, feeling passionately that valuable innovation skills developed through unstructured play such as risk-taking, exploration and freedom of thought, were becoming endangered. establishing an 'extraordinary school.' This vision led to the establishment of a school where all learning is grounded in STEM-centred play-based tinkering pedagogy.

Frank, William, and Maurice all applied a creative mindset, and were comfortable overseeing a teaching and learning program that was considered unconventional by their peers. In fact, these leaders felt a sense of accomplishment from designing and experimenting with the STEM learning, all actively engaged in the program and open in sharing their innovative ideas with colleagues beyond their schools. Frank was frequently invited to showcase his STEM program at universities and hosted visits from personnel from his education Department as well as other schools both locally and internationally. William showcased his work as a "lighthouse" STEM program to other schools in his system and coordinated a STEM professional learning group to share his knowledge and connections with colleagues. Maurice plays a leading role in a network of school leaders and teachers who aim to create alternative learning experiences and share the result of their learning innovations with each other.

All leaders extended their creative approach to find solutions to barriers that were presented. For Frank and William these were barriers largely presented by school system requirements and for Maurice the barriers his school faced related to traditional educational thinking by parents. Frank experienced resistance to his program by his superiors, with questions surrounding the adequate coverage of mandatory subject areas when students were spending significant periods of time engaged in the STEM room learning. This was complicated by the fact that in his jurisdiction, there is no specific mention of technology or engineering as subjects in the curriculum documents. Frank relayed that he had the experience at that stage in his career to provide him with the deftness to massage the pressures presented by Department inspectors and demonstrate that mathematics and science were sufficiently timetabled without inhibiting the learning program. William's organic and flexible way of planning for STEM controversially left no room for the state mandated blueprint of teaching and learning, the "scope and sequence." He worked to overcome this by creating a system that checks off STEM learning that has been completed, rather than plans ahead, to enable flexibility while attempting to capture any gaps in learning throughout the year. This did not follow procedure nor meet the authority's requirements, but was enough to satisfy William and his team that student learning was not disadvantaged. Maurice's regulatory environment did not place barriers to innovation, however he applied a creative mindset to maintain his innovation-building, risk-averse philosophy in the face of pressures stemming from parent discomfort with the absence of formal assessment. Instead of succumbing to the pressure of parental expectation for testing, Maurice has established proactive means of communication and collaboration with parents in the school's vision and priority for educational outcomes, which does not equate to a score or striving for a correct answer on a test.

The teachers interviewed all offered the view that their innovative teaching was made possible by the relational and professional trust and autonomy that Frank, William and Maurice extended them as part of their leadership. Similarly, Antony, Bella and Phillipa felt encouraged by their principals to engage in pedagogical experimentation and supported to evolve their STEM teaching and learning through trial and error. All three school leaders clearly guided their schools in a way that fostered a culture of creativity and innovation with respect to the STEM program. Frank displayed an open-minded management style that promoted creativity, rewarded innovation and encouraged norm-breaking. He was vocal in his school, network of school leaders and in his broader online professional learning community about his desire for changed teaching practices for the broader benefit of student learning and his vision for teachers to "teach from the heart and not from the book," reflecting his philosophy beyond the content and disregard for pressure provoked by academic results in tests. William's leadership style was one of support and pressure, in which he encouraged and supported creativity with high expectations for his staff to engage in his vision for student learning. He modelled the idea that mistakes are valuable learning opportunities, with critical reflection and evaluation key to his school's constantly evolving and improving STEM program.

William took a pragmatic approach when considering the impact of standardised test, refusing to feel pressured but instead measuring his success on the level of challenge students felt in their learning. Maurice modelled curiosity, courage and big picture thinking, inspiring experimentation in both teaching and learning at his school. While upholding a clear educational philosophy that guided the work of his teachers, this philosophy promoted risk-taking and teaching of original STEM content in inventive ways.

The STEM teachers all reported a strong sense of freedom and autonomy in their role. Antony acknowledged the professional trust of his principal as instrumental in his ability to institute the innovative STEM program, noting that many other leaders would not be as supportive. He also felt that Frank's subsequent enthusiasm for and involvement in STEM learning helped the program flourish. Bella compared the level of autonomy she was afforded in William's school with that of her previous school, reflecting that in her current role she has the ability to teach in a way that aligns with her personal philosophy. In her previous role she felt constrained to teach in a uniform unimaginative way; working in William's school she is able to be creative in seeing her students challenged, which provided a great deal of job satisfaction. Similarly, Phillipa has experienced a more constraining, innovation limiting environment which made her appreciate the freedom for her to be creative with learners, which she believed in turn allowed her learners to be creative. The school encourages its teachers to say "yes" to students and to let the students be hands-on and driven by their ideas.

The stories uncovered in the case study schools showed strong evidence of a learning discourse and culture of professional learning inquiry and professional growth. The schools provided a structural framework for the teachers to grow their STEM pedagogy, including formalised time for research and experimentation and ongoing and explicit practices of reflection and giving and receiving feedback. All six educators were either engaged in or leading networks of inter-school STEM professional learning, including frequent showcasing and sharing of practice. Again however, despite the clear learning culture, it was apparent that some of the other teachers in the Australian and Irish schools were not enthusiastically engaged in the STEM professional learning or teaching. This may or may not be a reflection of leadership or culture in the school, which will be discussed in the next section.

However, it must also be noted that all principals of the STEM schools indicated that at times not all of their staff were on board with their vision, and for two of the schools that this caused some difficulty with the success of the programs. In this sense, while there was a definite culture of creativity within the schools, it did not extend to all staff. Frank regretted his failure to get his other teachers motivated and "on board" to change. Antony reflected that perhaps the program could have been scaffolded to be more inclusive and simplified to support the teachers who did not feel comfortable with the experimental aspects of the innovation. William, on the other hand, felt that the teachers that were resistant did not hold the requisite skill and were therefore not the right cultural fit. Maurice noticed some normalising tendencies or aspects of a traditional academic classroom creeping in as a consequence of changed learning environments during COVID, however this "problem" was addressed as soon as it was observed. Phillipa reflected that while there was a diversity of skills and approaches among the teaching staff, her school environment was not suited to all teachers.

5.2.1.2 Innovative Teachers. Previous work on innovation and teaching focused on the attributes, skills, values and behaviours demonstrated by teachers (Cumming & Owen, 2001; Ferrari et al., 2009; Messmann & Mulder, 2011; Nadelson & Seifert, 2016). This study determined two key innovating fostering factors related to teachers, including the enthusiasm of teachers for innovation as well the aptitude and skill of teachers to be creative and innovative. Cumming and Owen's (2001) work outlined the personal attributes, skills, knowledge, values and strategies as strengths found in innovative teachers. Messmann and Mulder (2011) and Nadelson and Seifert (2016) have further studied innovative behaviours typically demonstrated by teachers that engage in innovative instructional practices . Ferrari et al. (2009) found that teachers need to value, understand and possess skills in innovation and creativity in order to promote innovation in education. Delphi panelists also identified innovation fostering factors relating to teachers as embodying such things as an attitude that embraces change, a desire to be inventive and a commitment to continual learning.

The experiences shared by the six participants in the STEM case study schools indicated that they all embodied the enthusiasm and aptitude for innovation described above. Antony's reported experiences showed him to be experimental and entrepreneurial, seeking improvement and new professional challenges both outside and inside school. He and valued the innovation skills that STEM learning could develop for the students as well as his own teaching practice. Despite acknowledging that he was in the late stage of his career, Frank actively sought opportunities to develop himself professionally and to share practice with others. He was committed to change, and saw value in being at the forefront of student-led STEM learning in his jurisdiction. William was continually critically reflecting on his work, refining his approach and seeking new opportunities for growth for himself, his staff and his students. His commitment to innovation in the teaching and learning as well as the administrative elements of the STEM program, in addition to his courageous approach in changing the focus of the school in the face of strong school community opposition, appear to demonstrate his deep-seated need to be creative, challenged and stimulated in his work. This is also reflected in his varied set of skills and work history. Bella's story depicts her as having a similar values and drive to William, describing herself as passionate and more "out there" in terms of "giving things a go" in relation to her peers. Her enthusiasm for innovation in education is evident in the fact that she was not satisfied to stay teaching in an environment where practices were uniform and regimented, instead seeking further qualifications in play therapy and subsequently teaching work in more flexible and personally rewarding environments. This commitment to innovation and creativity is also demonstrated in Phillipa's story, in both her teacher training and then choice of school environment. Viewing herself as a designer and co-creator, and teaching as an exploratory and experimental activity, her commitment to reflection and evaluation is evident. Maurice's experiences show him to be a philosopher and an educational entrepreneur, exhibiting altruism and passion. He established a pioneering STEM learning environment to encourage the essential factor in creativity he saw as the missing link in school - risk-taking. The school has continued to evolve and expand its innovative educational offerings guided by Maurice who blogs, writes books, presents and shares his enthusiasm for tinkerking pedagogy internationally.

The STEM case studies also identified that when teachers do not exhibit or develop the innovation fostering aspects outlined (see 4.1.3.2), there can be difficulty in initiating and maintaining innovative K–6 STEM learning. This will be discussed as an innovation limiting factor in section 5.2.2.

5.2.1.3 Experience Outside School. An innovation enhancing factor that emerged from experiences uncovered in the narrative case-study is that of teachers' experiences outside of school. All educators in the narrative case study schools attributed factors outside of school as a significant factor in motivating and guiding their innovative approach to STEM teaching, with five of the six attributing this to work experiences outside of teaching and schools.

Antony credits taking some time away from the teaching profession after 21 years as a motivator in his involvement in the eventual building of the STEM space. During this career break Antony was working to develop a "start up" digital learning company, meaning that he was engaged with both designing technology enhanced learning and in developing entrepreneurial skills. Antony employed these skills in the ideation of the STEM room and in seeking ways to fund its activities. However, he felt that the biggest role that his outside experience played in terms of influencing his innovative teaching was in being part of the real world outside of the institution schooling, and seeing the real-life skills required to be developed in schools. Another teacher in the narrative, Bella, reported that the time she spent away from teaching learning about play-based therapy re-energised her into the profession and affirmed for her the approach she wanted to take in her teaching moving forward. She needed to feel a sense of autonomy and creativity, and an ability to experiment and take risks in designing learning for students in a way that develops the skills required to be successful beyond academics.

William, Maurice and Phillipa all entered the education sector with previous careers in other fields, although interestingly with work experiences in STEM. William believes that his experience in architectural design and strategic marketing prior to his career in teaching were strong influences on his leadership of STEM teaching. Maurice was formerly a "technologist" and software engineer in a large international tech firm. He has no formal education in software engineering, having taught himself the skills of software design, and had a lifelong interest in tinkering prior to establishing the STEM camp and eventually STEM-centred school. Phillipa spent the first ten years of her adult working life as an interior designer and her pre-teaching career assists her in drawing parallels between the design process, the teaching process and the learning process.

There appears a lack of literature on the impact of career break, otherwise trained or career change teachers on innovation in schools. The most direct found in relation to this topic is that by Varadharajan and Schuck (2017), who established “career changers” as possible “change agents” and seemingly well set up to prepare students with a range of skills for life beyond school to work in an increasingly globalised world. There has been some work that references the recruitment of science and mathematics graduates as a strategy to enhance the quality of STEM teaching (Watters & Diezmann, 2015), however this is in relation to the experiences of STEM career changers rather than their effectiveness of STEM teachers nor on any relationship to innovation.

Another link can be made to the Teach for America (TFA) initiative, which deliberately recruits university graduates from other vocational areas for its novice teacher program. Its purpose is to institute a diverse range of skilled leaders into the education sector to drive an entrepreneurial approach to inequity and underachievement in education. According to Higgins et al. (2011), there is a distinct lack of research that evaluates the success of TFA in its recruits success in enacting innovation and change, although these authors did find that a large number of TFA recruits become leaders in the education field.

5.2.2 Innovation-Limiting Factors

The Delphi study identified factors that can limit innovation in schools. Among the macro level factors include: prescriptive mandatory curriculum, high stakes standardised testing, top-down prescriptive teaching programs and government mandated systems of accountability such as school inspections. Meso level factors include lack of support from leadership beyond the school, excessive school system compliance requirements, top-down school mandated prescriptive teaching programs, lack of support from school leadership, micro-management by the leadership, lack of learning culture; and insistence on complete consistency between teams of teachers.

As is to be expected of a modified Delphi study that is designed to test ideas that come from research, many of these factors are known in the literature on innovation in schools. The innovation limiting aspects of school systems that are governed by education policy influenced by global neoliberal reforms, such as prescriptive mandatory curriculum, high stakes standardised testing, top-down prescriptive teaching programs and systems of accountability, are well noted in the literature (Au, 2011; Banaji et al, 2010, 2013; Berliner, 2011; Biesta, 2017; Bloom & VanSlyke-Briggs, 2019; Gannon, 2012; Giles and Hargreaves, 2006; Gorur, 2013; Greany & Waterhouse, 2016; Hargreaves & Shirley, 2009; Harris & Jones, 2018; Knight, 2020; Lingard & Lewis, 2015; Lubienski; 2004; Nordgren, 2015; Olivant, 2015; Sahlberg, 2006, 2009, 2010, 2016; Savage, 2017; Schoen and Fusarelli, 2008). As outlined by Delphi panel experts and in the literature, the standardisation and resulting accountability that has been used as a means of improvement in school systems in the past decades has meant that the factors mentioned above work to keep schools uniform and in line in order to encourage a set of results or standards in a narrow set of subject areas. This has worked to limit various areas of educational innovation, including working to regulate how teachers design teaching and learning in their classrooms (Hargreaves & Shirley, 2009; Sahlberg, 2009, 2010). For STEM learning in particular, the fact that mandated curriculum sees that subjects are structured, timetabled and assessed separately can be a limiting factor in some schools (Blackley & Howell; 2015; Ferrari et at, 2009; Herschbach, 2011; Honey et al. 2014; Nadelson & Siefert, 2017; Willams, 2011).

School level barriers to innovation found in the Delphi study were identified by the expert panelists. There is little contemporary research that specifically addresses the school level factors that inhibit innovation in schools. Rather, much of the research is coined in terms of the enablers of innovation. The literature that does exists confirms the key message that emerges from the Delphi findings, in that when the organisational features of the school focus on custody and control it impedes change innovation (Banaji et al, 2010, 2013; Boyd, 1992; Ferrari et al. 2009; Rahmat, 2020).

When considering barriers to innovation that emerged in phase two of the research, it must be noted that it is more difficult to discuss limiting factors than fostering factors when examining schools that have successfully implemented an innovative STEM program. Nevertheless, it is useful to discuss the elements of the Delphi findings that played out in the STEM case study schools. Also, before discussing the limiting factors uncovered in the schools, it is important to highlight that the Delphi study also found that innovative teachers and school leaders can typically find a way to navigate limiting and constraining factors in order to be innovative in schools. In this sense, innovative teachers and school leaders view the challenge of innovative teaching and innovation in schools in an optimistic light and tend to disregard inhibitors as small obstacles or a mere hindrance, rather than a factor that limits their success. One insight from a Delphi panelist encapsulated the sentiment evident in much of the panelist commentary:

> Innovative teachers can be slowed, but rarely stopped. Individual constraints can be seen as more of a nuisance and challenge. Truly innovative teachers overcome most obstacles, using their innovation skills to circumvent these challenges.

This sentiment certainly played out in the STEM case study schools. Some challenges were identified, but they were not considered detrimental to the success of the programs.

5.2.2.1 Parental Expectations. One inhibiting factor that emerged in the narratives of the case study schools involved the perceptions and priorities of school parent communities. That is, the *pushing boundaries and moving away from norm and convention* that occurred in the schools inspired nervousness in some parents, and parental expectation was mentioned in each case study narrative. This insight was not specifically identified in the Delphi study, which could point to this phenomena being specific to K–6 STEM learning and warrants further explanation. There is little research specifically linking the role of the school community with a school culture that supports innovation. Greany (2018) found that the way that parents perceive and value innovation impacts on the success of innovation and change in schools. According to Gellert (2005), while identified as a factor in research on innovation and change in schools, parents rarely considered in innovation and reform efforts.

Innovation limiting pressure from parents was least evident in the Irish school, which could be a result of the trust the community held in the long-term school principal, the way the program was executed or communicated and/or a contextual or cultural factor unexplored in the study. Frank referenced the parental expectation that teachers use text books in their teaching, which is contextual factor previously been referenced in Irish literature as a barrier to integrated STEM learning (Delahunty et al. 2021), however neither Frank nor Antony named this as a challenge to the STEM program. Parental "resistance" and "push-back" featured more heavily in the Australian STEM story, which details that William's school community were unconvinced of the academic rigour of the STEM program and feared it would leave the more gifted students disadvantaged. William took this expression of concern and discontent as feedback rather than a barrier to innovation, improving the academic challenge aspect of the STEM learning in subsequent iterations. While Maurice considered traditional educational beliefs held by parents and the resulting pressure as the most significant challenge in his innovative STEM learning environment, he like William has used this push-back as feedback. Maurice did not feel the impetus to change pedagogies or practice, but rather let the feedback inform operational aspects of the school, such as messaging and proactive communication about the educational values integral to his model of STEM learning.

These examples point further to innovation in schools as part of a learning process. Further, the insights provided in the case study schools highlighting the importance of parent community acceptance and support for innovative STEM learning practices as well as the need for proactive parent communication suggests that culture exists beyond the school walls. That is, the *culture of creativity and risk-taking* as part of school leadership and culture, which is a key innovation fostering factor in K–6 STEM learning, extends to parents as well as teachers and students. This indicates that parents are an important stakeholder when promoting thinking about student learning that is less preoccupied with student test results and more supportive of teaching in ways that develop in students a broader set of skills, ensuring an "emotional spirit" (Dewey, 1916) of STEM learning innovation in the broader school community.

5.2.2.2 System-Mandated Standardisation. Two of the three case studies schools identified standardisation as a potential innovation limiting factor. Frank was questioned by system leadership with regard to the adequate coverage of mandatory subject areas when students were spending significant periods of time engaged in the STEM activities, much of which were not officially part of the curriculum. Frank made light of this obstacle, an attitude that he credited to his years of experience, and was able to appease his inspectors by demonstrating that mathematics and science were sufficiently (albeit creatively) timetabled without inhibiting the learning program.

In similar fashion, William was not preoccupied with external limiting factors but was instead critical of his own actions, reflecting his desire to continually improve and innovate. William's flexible way of planning for STEM controversially necessitated removal of a mandated framework for planning. William's student-centred and pragmatic approach disregarded the specifics of the planning requirement, and designed a “work-around” he was satisfied with. William also took a pragmatic approach when it came to national standardised tests, despite increasing pressure within his school system to deliver on associated targets. He was more concerned that his students felt challenged and engaged in quality learning than an annual test, and expressed that when results fluctuate in these tests it is more of a reflection of the makeup of different cohorts of students than the quality or effectiveness of teaching practices. The teacher at William’s school Bella, on the other hand, did feel some pressure with regard to the standardised tests and the evaluative reflection this may have on her teaching. She stressed, however, that she would not do what has become a phenomenon in many schools impacted by standardisation reforms, which is “teach to the test” (Lingard & Lewis, 2015). Bella emphasised that despite the pressure of measurable academic results, she prioritised teaching her students for life beyond school to develop the skills and understanding for success in the “real world”. This illustrates that Bella did not act with the view that standardisation is a factor that greatly limits her innovative teaching of STEM.

5.2.2.3. Teaching Staff. One system level factor that did present as short-term inhibiting factor and highlighted a potentially wider limiting factor for many schools with regard to STEM teaching and learning, relates to teaching staff. Analysis of findings from phases one and two raise considerations for innovation in STEM learning in relation to planning for teacher “buy-in” along with issues associated with teacher skill, aptitude and enthusiasm for innovation.

Antony reflected that in his school the STEM learning did not become a whole-school program, with both he and Frank acknowledging that the other teachers in their school lacked interest in becoming involved. This raises the question as to whether this aptitude and enthusiasm (innovation fostering factors) can be developed in teachers to support innovative approaches to STEM learning. Nadelson and Siefert (2016) suggest that with appropriately designed and delivered intensive integrated STEM professional development, teacher innovative behaviour associated with implementing innovative programs can be developed. Antony offered two possible explanations for the reluctance of the teachers in his school to be involved, including their traditional ideals and their perceived lack of inclusion in the program. Various literature has shown that for teachers to successfully implement an innovation it must be congruent with their values and beliefs (Ferrari et al. 2009; Holdsworth & Maynes, 2017; Savina ; 2019; Wallace and Priestly, 2011). In alignment with the traditional thinking barrier that

Antony described, psychological and professional barriers such as traditional conservatism and stereotypical thinking, and a tendency toward reproductive rather than creative thinking, can prevent teachers from engaging in innovation (Savina, 2019). However, what could be seen as reluctance or inflexibility may in fact be an issue of congruence with teacher beliefs, and therefore innovations can be successful when teachers have an opportunity to implement them in line with a personal process best suited to their own ability and beliefs (Holdsworth & Maynes, 2017; Wallace and Priestly, 2011). Antony made an attempt to include the teachers in the program by providing "team-teaching" modelling and support, but he felt that his efforts were too late to achieve the teacher buy-in. Both Frank and Antony reflected that they would design the program to be more inclusive from the outset if they had their time over and make every classroom in the school a STEM room and every teacher a STEM teacher.

In William's case, he felt that his initial teaching staff did not have the knowledge or skill to implement STEM learning in a way that appropriately served the students. He also reflected that the nature of his smaller school meant that his teachers did not have the team around them for the amount of collaboration and support required to provide the necessary up-skilling and motivation. Therefore, in William's context, he came to believe that under these conditions it was especially important for to have the appropriate teaching staff available. This aligns with previous studies that have found teacher disposition to innovation (including willingness to learn) and expertise in STEM content knowledge (STEM teaching capability) as key to the success of an integrated STEM teaching and learning program (Becker & Park, 2011; Gonzalez & Kuenzi, 2012; Honey et al, 2014; Nadelson & Siefert). William's concerns with regard to the STEM teaching capability and disposition towards innovation of his staff is made even more apparent when considered in comparison to the recruitment flexibility and breadth of skill among teaching staff in Maurice's highly innovative school. Phillipa identified that the creative approach to teaching is not a natural inclination in all teachers, with some more oriented to order, organisation and tradition rather than the flexibility, spontaneity, inquisitiveness that is better suited to her school environment. Maurice and Phillipa acknowledged that the STEM learning approach in their school relies on teachers embracing creative designing and learning, which requires a certain level of interest and aptitude. They also credit the wide range of skills and experiences among the educators as integral in the success of the program.

These examples highlight was has been uncovered in previous research on innovation in schools, in that while professional learning and support can assist the effective implementation and maintenance of innovative teaching (Chang et al. 2011; Nadelson & Siefert, 2016; Paletta et al. 2021), ultimately whether or not teachers develop professionally to support innovation "depends on the characteristics of the teachers themselves" (Geijsel et al. 2001 p. 133), such as teacher comfort with ambiguity and calculated risk taking (Nadelson et al., 2015) as well as the characteristics of the environment in which the teachers work and function (Thurlings et al., 2014). While it is important to recognise that there are ways to engage reluctant teachers to innovation (Holdsworth & Maynes, 2017; Savina ; 2019; Wallace and Priestly, 2011), the challenges uncovered in the STEM case study schools highlight the need to better explore the impact of flexibility in teacher hiring policies on innovation in K–6 schools. This is because, while schools as learning organisations should continue to employ professional development to enhance the innovation capacity of teachers, some teacher behaviours "may be very difficult to influence, as the behaviours may be deeply rooted in the individual or may be out of their control and therefore difficult to modify" (Nadelson & Seifert, 2016, p. 63).

Innovation in relation to flexibility in hiring teachers is discussed in some literature in relation to charter schools as outlined in Section 2.3. of the literature review (Burian-Fitzgerald & Harris, 2004; Preston et al 2012), particularly in terms of charter schools existing outside teacher collective bargaining agreements and teacher certification requirements. There has also long been concern about the shortage of teachers qualified or equipped to teach STEM in Australia and internationally (Borgerding, 2015; Fraser et al.2019; Goldhaber, 2015; Hunter, 2020; Hutchison, 2012; Lu et al. 2019; Mills et al. 2020; Timms et al. 2018).

While there has been some work on the importance of recruitment of "STEM-talented" or STEM literate practitioners to teacher education (Borgerding, 2015; Lee & Nason, 2013; Watters and Diezmann), there appears to be a lack of literature investigating the influence of teacher hiring policies and processes in relation to K–6 STEM teaching and any associated impact on innovation in schools. It is well highlighted in the literature however that it is within the realm of control of the school to implement STEM-specific professional learning to up-skill existing teachers (Fraser et al.2019; Hunter, 2020; Hutchison, 2012; Lembo, 2016; Lu et al. 2019; Mills et al. 2020; Timms et al. 2018) and of particular importance to the subject of this study, STEM professional learning that targets K–6 teachers (Hunter; 2020; Lu et al. 2019).

5.3 Conclusion

In this chapter I sought to restorify and narrate the findings in relation to the research questions, discussing the issues and insights arising from the intersection commonplaces (Connelly & Clandinin, 2006). The story unfolded to reveal what constitutes innovative teaching and school leadership, and relate these to the STEM case study schools. The chapter discussed the insights that arose in relation to both phases of the study, producing three aspects including innovation as a learning process, innovation as a creative process and innovation as an outcome for students. The discussion revealed that the key innovation enhancing factors for innovative K–6 STEM learning relate to leadership and culture and to teacher attributes (see 4.1.3.2). The study also found that innovative educators are less preoccupied with factors that prevent innovation and tend to overcome obstacles that they are presented with. Nevertheless, the discussion revealed some limiting factors that can be considered when implementing innovative approaches to K–6 STEM. The final chapter will provide a conclusion and summary of insights, as well as the limitations of the study and recommendations for future research.

Chapter 6

Conclusion

> Despite STEM education being in a prime position for preparing students for disruption, we are not realising the potential of these disciplines. STEM education needs to be at the forefront of disruptive and innovative thinking, just as companies need to continually innovate to survive or avoid a take-over. Companies cannot stand still in today's disruptive climate; nor can countries; nor can education. (English, 2018, p. 2)

The previous two chapters have presented and discussed the insights that emerged from both phases of the study, revealing what constitutes innovative teaching and leadership in schools and offering a deeper understanding of what facilitates STEM learning innovation in K–6. In narrative terms, this chapter works as both an ending and moral to the stories of K–6 STEM learning innovation examined in this study. It outlines the conclusions and implications drawn from the findings and discussion, references the limitations of the study and details the significance of the research in adding to the literature and informing practice, policy and future research.

6.1 Key Insights and Implications

This study has fulfilled two important aims, serving to build a shared contemporary understanding of innovation in schools and to uncover factors influencing innovation in K–6 STEM learning. A comprehensive definition of school innovation was produced in phase one of the study, which in the wider context of the research has established a criteria for evaluating the experiences of STEM learning innovation uncovered in phase two, as well as innovation in schools more generally. This was achieved via a robust Delphi study which elicited the perceptions of experts in the field. The phase one findings define in detail what constitutes innovation in a school context, and elucidate the factors that foster and limit innovative teaching and innovative school leadership. In phase two, the study went on to analyse and relay the stories of experience of K–6 teachers and school leaders engaged in STEM learning innovation. The stories were collected from schools in different education systems with contrasting educational traditions and policies, uncovering the nuanced contextual influences on innovation. The following research questions guided the research:

1. How is school innovation defined by experts in the field?
2. What are the factors that foster and limit innovation in schools?
3. What factors enhance or prevent innovation in K–6 STEM learning?

A synthesised analysis of the findings from research phases one and two were discussed in the previous chapter. In this chapter, the insights and implications are presented within the categories: (1) school innovation and (2) K–6 STEM learning innovation.

6.1.1 School Innovation

The study has delivered a contemporary understanding of innovation in schools. This understanding applies to innovation as it relates specifically to a school context rather than wider educational settings, and expands on other definitions in the literature that narrow in for example on teaching approaches and curriculum or technology enhanced learning. The evidence from the study revealed the multilayered nature of school innovation, identifying that innovation should be viewed as both a process of teaching, learning and school administration, as well as an outcome of learning. In addition to the definitions of school innovation, innovative teaching and innovative school leadership, significant insights emerged from the study that present a number of implications for teachers, school leaders, system leaders and policymakers. These include findings that relate to innovation being viewed as professional learning, leadership and culture fostering school innovation, the idea that creativity in teaching and school leadership should be valued and the understanding that school innovators see challenges, not barriers.

The study found that innovation in school education *is* education, in that the process of innovation leads to professional learning. To date, innovation in schools has largely been considered a function of change management (Darling-Hammond, 2008; Fullan, 2002; Hallinger, 2003; Resnick et al, 2010; Senge, 1990; Senge et al 2012; Silins & Mulford, 2002). This study has built on the work of Bakkenes et al. (2010) and Westbroek et al. (2019) to produce compelling evidence that just as innovation has been recognised as a process of workplace learning in other organisations (Beckman & Barry, 2007), innovation should be seen in schools as a process of professional learning for teachers and school leaders. In this sense, the evidence in this study suggests that innovation should be respected and utilised as deliberate method and mode of workplace professional learning in schools by a process of experimentation/ideation, design, iteration, experience, mistakes, feedback and reflection.

The study also uncovered four elements of leadership and school culture associated with innovation in schools; innovative leadership by the principal; a culture of creativity and risk taking within the school; teacher autonomy; and a culture of professional inquiry and exposure to education research literature and evidence-based ideas. Other studies have identified the importance of school leadership in supporting innovation in schools (Buske, 2018; Moolenaar et al. 2010; Park, 2012; Pixie et al. 2012; Riveras-León and Tomàs-Folch, 2020; Vaara and Lonka, 2014; Wibowo and Saptono, 2018), and this study has identified a model of innovation fostering and supporting school leadership as detailed in Section 5.2.1, which is characterised by *trust, experimentation, aim, mindset and solutions* (TEAMS). The TEAMS acronym is meaningful in that the study found that school leaders need to work in partnership with teachers to successfully achieve innovation in their schools. The study has determined that an innovation fostering culture embodies an open-minded management style that promotes creativity, acknowledges and rewards innovation, encourages movement outside the boundaries of convention and promotes thinking about teaching and learning that develops in students a broader set of skills than those determined by accountability tests.

Another significant finding of the research is that innovation can be viewed as an act of creativity in teaching and school leadership, which is a tendency or approach to teaching or leadership that involves morphing ideas into something contemporary, interesting or effective in the administration of schools or in the classroom. This has important implications for the way that innovation is viewed as an aspect of leadership by school systems. To date, innovation as a feature of school leadership has largely been considered a concept of improvement in the context of greater education reform, adapting rather than disrupting current practices to see improved results as measured by standardised means. This study has added to the literature raising important questions about the nature and value of innovation within the restrictive institutional and political school environment. A unique implication of this study is the possibility that innovation could be viewed in schools as a creative process considered outside the moral or ethical ideals that are usually implicit in educational actions, and in particular improvement linked to neoliberal school reform. That is, rather than being viewed with suspicion, creativity could be added to the lexicon of innovation in schools much as it is when viewed as a valuable feature in solving problems in technological and economic realms.

The study produced a further interesting insight that perhaps explains why there is little contemporary research that specifically addresses the school level factors that inhibit innovation in schools, and also why much of the research is predominantly coined in terms of the enablers of innovation. That is, while there are certain organisational features that can impede change innovation in schools (Banaji et al, 2010, 2013; Boyd, 1992; Ferrari et al. 2009; Rahmat, 2020), the study has delivered the understanding that innovative teachers and school leaders approach their work with a standpoint that they can bypass innovation limiting factors. The evidence in this study suggests that innovative teachers and school leaders view the challenge of school innovation in an optimistic light and tend to disregard many innovation inhibitors as small obstacles or a mere hindrance, rather than as factors that can significantly limit their success. In this sense, school innovators do not see *barriers* to innovation, but rather *challenges* to innovation, applying a distinctive lens of possibility to organisational requirements and restrictions.

6.1.2 K–6 STEM Learning Innovation

The results of the study have added valuable insights to the field of knowledge of K–6 STEM teaching and learning. Importantly, the research has allowed an understanding of the factors that enhance or prevent innovation in the teaching and leadership of K–6 STEM. Among the findings, three aspects have emerged particularly noteworthy in shedding further light on factors that impact on innovation in K–6 STEM. These relate to teacher skill and buy-in, teacher and school leader experience outside of school and parents as part of an innovative STEM learning culture.

This research supports the idea that just as there is a combination of skills desired in a future innovative workforce (and therefore these skills need to be nurtured in students) there are particular attributes demonstrated by innovative teachers and school leaders, confirming the findings of previous research on attributes, behaviours and beliefs of innovative teachers (Borasi & Finnigan; 2010 Cumming & Owen, 2001; Ferrari et al., 2009; Holdsworth & Maynes, 2017; Messmann & Mulder, 2011; Nadelson & Seifert, 2016; Priestly, 2011; Savina, 2019; Thurlings et al., 2014; Yemini et al, 2015). Further, this study has made the link between the innovation compatible attributes of educators (including enthusiasm aptitude and skill for innovation) and the success of innovative approaches to K–6 STEM learning. Importantly, the experiences in the STEM case study schools provided the insight that when teachers do not demonstrate the innovation fostering attributes identified in the study, or when there is no plan or capacity to create the conditions for nurturing these attributes, there can be difficulty in initiating and maintaining innovative K–6 STEM learning.

The lessons that have emerged from the STEM narratives include a consideration of the inclusiveness of the design and implementation of STEM programs, which should encourage teachers to engage with and implement STEM learning innovation in ways that suit their teaching beliefs. The STEM school stories also highlight the need for STEM professional learning to nurture teacher engagement with innovative approaches to change some of these innovative teaching behaviours (Nadelson & Seifert, 2016). In addition, the stories draw attention to the possibility that teacher education as well as teacher recruitment policies could play a role in ensuring success of K–6 STEM learning innovation.

The study also established a link between teachers' work and study outside of school and innovative approaches to K–6 STEM learning. An implication of this link is the possibility that work experience outside of school, in terms of educators taking a career break, and/or entering the field after work or study in other professional arenas, can motivate and guide innovative K–6 STEM teaching and leadership. This finding contributes to the discussion by Varadharajan and Schuck (2017), who established "career changers" as possible "change agents" in schools.

Further, the study produced evidence establishing the important role that a school's parent community can play in enabling a creative, innovation-fostering K–6 STEM learning culture. Extending the findings of Greany (2018), this study found that parental understanding and expectation can impact on the realisation of a school's innovative vision for STEM learning in a K–6 context. The findings suggest that parents should be considered key stakeholders in an innovation fostering STEM learning culture, and highlight the importance of communication and education for the parent community in establishing shared understandings and avoiding assumptions that can work as barriers to success.

6.2 Limitations

The story of K–6 STEM learning innovation uncovered in this study is limited to the experiences and perspectives offered by the participants. The findings are therefore not intended to be widely generalisable, but instead to offer insights that can inform approaches to innovation in K–6 STEM learning, and indeed innovation in schools. The study therefore does not claim to tell the entire story, nor does it intend to act as an end to the story. Also, recognising the temporal nature of sociocultural research, it is important to note that this study captures sentiment and experience with regard to an evolving phenomenon at a particular point of time.

A thorough analysis of the methodological limitations inherent in the study design is included in Section 3.5. Despite planning for the mitigation of these, there are some potentially limiting aspects to the study. Gender representation was not a criterion for the selection of participant in either phase of the study, and perhaps further consideration could have been made to this aspect of the makeup of the panel of experts. In addition, the STEM school cases were selected after being nominated by peers for their employment of innovative STEM practices. Here it is noted that what is innovative at one school, or in one school system, is not necessarily innovative at another (Tytler et al., 2011). This is particularly true in the passage of time when an innovation transitions from the fringe to the mainstream (Christensen et al., 2015). Nevertheless, the insights are valuable in examining the contextual factors influencing STEM learning innovation K–6.

In addressing the limitations, I reiterate the complexity inherent in the research topic that was acknowledged in Chapter 1, in that the problem and phenomena being investigated in the study exists at the intersection of political ideology and educational philosophy. As such, some readers of the work may experience difficulty with the tensions between neoliberal purpose and control at the heart of this study (see Section 1.5). At the conclusion of the study however I am further convinced of the importance of discussion of the disconnect that exists between the imperative to school innovation and the realities of the standardisation agenda faced by schools.

The COVID 19 pandemic emerged in the middle of the study. Phase one had been completed, and phase two had only just begun. There was an intention to visit and engage further with the STEM schools, and to interview the participants face-to-face, and there was also an intention to include a further case study school from the UK. COVID appeared to change the nature of schools' willingness to engage with research, as the focus in many was on managing the teaching and learning in the midst of changing practices that the COVID pandemic necessitated. As such, it was difficult to secure the involvement of schools. None of these outlined factors related to COVID served as an ultimate impediment to the research, nor did they impact the trustworthiness of the study. They did increase the length of time taken to complete the work. As such, it is important to recognise that the expanding interest in the topic during the time of the study, in addition to the breadth of topics related to the study, make it difficult to be assured that all relevant literature has been considered.

6.3 Contributions of the Study

The study contributes to our understanding of innovation in schools and innovative K–6 STEM learning to inform policy, practice and research. The research is timely because of the increasing value attributed to the building of foundational STEM knowledge for K–6 students and the global call for rethinking and reinventing an outdated school education system that has not kept pace with technological, economic and societal change (Aslan & Reigeluth, 2013; Beare, 2001; Christensen et al., 2008; Fullan & Langworthy, 2014; Hargreaves, 2003: Istance, 2011; OECD, 2001, 2010, 2016a; Peters, 2003; Sawyer, 2006). The research findings from this study are important because they highlight the possibilities and difficulties of K–6 STEM learning innovation and innovation in schools more broadly in the context of the other contemporary global policy influence, standardising education reforms.

This study has served an important purpose in highlighting stories of STEM learning innovation primary (K–6) settings. K–6 context of the study is particularly beneficial, given the recent calls for early exposure and intervention in STEM learning. This study serves to add to the emerging but still lacking body of work addressing issues of STEM teaching and learning, and in particular innovation in STEM, in the primary education space.

A significant contribution to the literature is the comprehensive contemporary understanding of innovation in schools that was uncovered in the Delphi study. The findings reveal detailed aspects of the process of innovation in schools, and expand on previous research that highlights the importance of innovation in teaching to innovation as an outcome in learning. The study has also confirmed that innovation in schools is strongly influenced by leadership and culture as well as the skill, aptitude and enthusiasm of teachers. In addition, the study offers several new insights (outlined above) into both innovation in schools and K–6 STEM learning innovation that can serve to inform teaching and leadership practices, education policy and research.

The findings have generated a model representing the innovative behaviour, and innovation supporting behaviour, of school leaders defined as Trust, Experimentation, Aim, Mindset and Solutions (TEAMS). In addition, the study has identified an explicit and comprehensive shared understanding of innovative teaching confirmed by experts in the field. Both the model of innovative school leadership and the definition of innovative teaching emerging from this study can assist educators, researchers, policymakers and system leaders in facilitating and evaluating innovation in schools, thereby supporting contemporary economic and social innovation imperatives.

Indeed, amidst a growing neoliberal policy environment of standardisation and restriction in education globally and particularly in Western nations, a discussion of the findings with reference to literature raises important questions about state and system features that value sameness in education practices and emphasise proficiency in a narrow set of foundational skills. The evidence from this study suggests that in order to promote innovation and creativity in our students and therefore future workers, creativity in teaching and school leadership should be valued. To reiterate the point made in earlier in the chapter, this study has determined that innovation should be viewed in schools as it is in economic realms, not as a concept of improvement for "excellence" against a standard model, but as an act of creativity in leadership and teaching practice that can potentially create new and more valuable possibilities.

It is against this backdrop that the other important contribution of this research should be considered. A synthesised analysis of both phases of the study found that teacher buy-in, skill and approach is important in K–6 STEM learning innovation, as are the attributes and skills of school leaders. This has implications beyond teacher professional learning and teacher training to recruitment practices and extends to policy ideology. The study has offered an understanding that a diverse set of skills and experiences should be valued among K–6 teachers and school leaders in order to deliver on the STEM narratives that governments and economic organisations promote. The findings imply that school systems should not only emphasise professional learning for STEM and for the types of capabilities and behaviours suited to innovation in teachers and leaders, but could also explore the value of flexibility in strategic hiring decisions in this regard.

The study also uncovered a link between innovative STEM teachers and school leaders and non-teaching experience outside of school. This suggests that there could be merit in system policies that value knowledge outside education; policies that encompass recruitment, career breaks and professional development. Additionally, the study has made the important connection between innovation and workplace learning and supports the idea that innovation is an adult learning process in schools as well as process of learning for K–6 STEM students.

Additionally, the study found that when risk-takers lead and teach K–6 STEM, the challenge of school innovation is viewed optimistically and without fear of barriers hindering the vision. That is, when innovators are employed as teachers and school leaders, a lens of possibility is applied to organisational requirements and restrictions. This suggests that risk-taking and entrepreneurism should be encouraged in the education sector if the school transformation narrative is to be realised, which also has important implications for future research, policy, teacher education and recruitment. That is, if policymakers continue to see education as essential to delivering vital innovative economic and social outcomes, and if indeed the call to action remains for schools to adapt in light of economic and social transformation, serious attention and consideration must be given beyond the behaviours and traits of innovative teachers and school leaders to include the type of thinking encouraged in schools and school systems.

The research has called attention to an area of caution for innovators in establishing and implementing K–6 STEM learning programs, and that is to pay attention to parental understanding. The findings established that even in schools where an innovative approach is highly valued by a parent community, there may be aspects of a program that are mismatched with parents' expectations as a consequence of their own experiences of learning. This highlights the need for strong communication to promote shared understanding of the school's vision and activities, and also to educate parents as to the philosophical link between the vision and teaching methods employed in the school. The study reinforces that a creative, innovation fostering culture includes parents as stakeholders, and provides the insight that parent consultation can improve K–6 STEM learning programs.

6.4 Future Directions

The findings from this study offer valuable evidence to inform the development of a model of innovation as professional learning for school teachers and leaders. The experiences uncovered in the case study schools, along with the insights provided by school innovation experts, suggest that innovation as professional learning involves experimentation/ideation, design, iteration, experience, mistakes, feedback and reflection. Further research should be undertaken to explore and validate an adult innovation learning process framework with these features and examine its effectiveness in teacher professional development in a variety of school settings.

There has been lengthy discussion in this study about the need to consider and plan for teacher skill and buy-in to create an environment for successful school innovation and in particular STEM learning innovation. Further research could examine more closely the links between the work of innovative STEM educators and work/study experience before teaching as well as non-school experienced during career breaks as described in this study. Further work is required to understand the impact of experiences outside of school on K–6 STEM learning in addition to K–6 STEM learning innovation, and any implications for policy and practice. Future studies on recruitment policies for both teacher education and schools in relation to STEM teaching and innovation could usefully explore how these may act as an innovation enabling or limiting factor in schools.

The insights shared in the findings of this study suggest that an important area of study could further examine equity issues surrounding STEM innovation and could explore the role of educational advantage, social justice and innovation in school more broadly. As outlined in the findings in Chapter 4, one of the participants in the STEM innovation case studies, William, revealed the idea that the affluence in his community, and the educational advantage that students bring with them to school, allowed more freedom for his teachers to experiment with their pedagogy. This revelation in William's story in Chapter 4 was not included in the wider story of STEM learning innovation discussed in Chapter 5, as it was not a resonant thread that emerged in the Delphi study or that was explored as part of the experience in the other STEM schools. What did arise from Maurice's story is that in his private school, the parents make a significant financial investment in exposing their children to the innovative STEM learning environment. Wilson (2020) raised concerns about the inequality of STEM outcomes for diverse learners and revealed the risk that the students who would benefit the most from innovative pedagogies may be more likely be on the receiving end of a more reductionist approach to STEM learning.

6.5 Concluding Remarks

The story of K–6 STEM learning innovation has unfolded in the chapters of this thesis. It is a story told in a time of transformation in society and education, where interconnected global economic and sociocultural policy priorities, innovation and STEM, have worked to form a call to action for schools to produce future STEM innovators. It is also told within a setting featuring arguably anti-innovation, standardising elements as part of the global education reform movement. The story concludes with an understanding that innovation, told using the example of K–6 STEM learning, can happen regardless of barriers presented at a macro, meso or micro level in schools. However, as the study has uncovered, there are various aspects that can enhance school innovation, and K–6 STEM learning innovation. The reader is therefore left to contemplate the possibilities if educators had the flexibility and mandate to act with the creativity that is described as an imperative outcome for students.

Appendix A

Delphi Round 1 Cover letter Information and Consent

Delphi Panel Survey - Innovation in Schools

Dear [FirstName],

Thank you for interest in my study, which is part of a doctoral research project at the University of Technology Sydney (UTS), Australia. You have been invited to participate because of your expertise in the field.

The delphi panel is an international study designed to collect and distil the anonymous judgements of experts to determine a consensus view and definition of innovation in a school context, including factors that enable and constrain innovation in schools. The study is part of a broader doctoral project on innovation in STEM education. The study has been approved by the UTS human research ethics committee (HREC), approval number ETH18-2833.

If you agree to participate in this delphi, it would involve responding to three short online surveys as part of a panel of experts. Your responses to the surveys will be confidential and de-identified.

The results of the survey will provide fresh insights into the factors that enable innovative teaching and school leadership, guiding future directions in primary schools.

Please click through for more information about participation and consent, and if you agree, to begin the first survey.

Rosie Di Mattia
[redacted]@student.uts.edu.au
[redacted]

Further Information and Survey

Delphi Panel Survey - Innovation in Schools

Participant Information and Consent

You are invited to take part as an expert panellist in an international Delphi study on innovation in schools.

This Delphi study is designed to determine a consensus view and definition of innovation in a school context and has been approved by the University of Technology Sydney (UTS) human research ethics committee (HREC), approval number ETH18-2833.

The study involves responding to three short online surveys as part of a panel of experts. Your responses to the surveys will be confidential and de-identified.

This first survey is to be completed now and will take approximately 10-15 minutes. It includes both closed and open-ended questions which will enable the collection and analysis of ideas from your knowledge and experience.

After this survey there will be two more 'rounds' distributed in the coming weeks, which will use largely closed ended questions and will each take approximately 10 minutes to complete. Before completing the second and third surveys you will receive a summary of de-identified responses to the previous round. The responses to round one will inform the questions in round two and so on. The aim of the second and subsequent rounds will be to evaluate ideas and develop consensus among the expert panellists.

Participation in the research project is voluntary and confidential.

If you have questions about the research, please feel free to contact me (details below) or A/Prof. Matthew Kearney, School of International Studies and Education, Faculty of Arts & Social Sciences, via [redacted]@uts.edu.au

If you would like to talk to someone who is not connected with the research, you may contact the UTS Research Ethics Officer on (02) 9514 9772, and please quote this number (ETH18-2833)

If you consent to your survey responses being used for this study as outlined in

the participant information sheet, please complete the survey by clicking 'continue' at the end of this page.

Thank you for considering this invitation. Your expert insights will be most valuable.

Rosie Di Mattia
PhD candidate
[redacted]@student.uts.edu.au
[redacted]

Appendix B

Delphi Study Participant Information & Consent Sheet

PHASE 1 DELPHI STUDY PARTICIPANT INFORMATION & CONSENT SHEET
How Do Primary Schools Cater For Innovative Futures in STEM?
UTS HREC APPROVAL NUMBER ETH18 - 2833

WHO IS DOING THE RESEARCH?

My name is [redacted] and I am a PhD student at UTS ([redacted]@student.uts.edu.au). My supervisor is Assoc. Prof. [redacted] (email : [redacted]@uts.edu.au Phone +612 [redacted]).

WHAT IS THIS RESEARCH ABOUT?

This research project aims to establish a definition and framework in understanding innovation in schools; both innovative teaching and more broadly what constitutes innovation in the school context.

This phase of the project involves a Delphi panel, which is an iterative approach designed to collect and distil the anonymous judgments of experts using a series of data collection and analysis interspersed with feedback.

The wider aim of the research is to identify how schools can allow for innovative teaching and leadership to produce the innovators of tomorrow. In particular, the broader study will identify recognisable factors that enable and constrain innovation in schools; specifically in the teaching of STEM in K-6 schools. It will do this via the perceptions and beliefs of teachers and school leaders, as well as experts in the field, about school and system level factors influencing innovative teaching.

WHY HAVE I BEEN ASKED?

You have been invited to participate in this study because you have been identified as an expert in the field of innovation in education.

IF I SAY YES, WHAT WOULD IT INVOLVE?

If you decide to participate, the Delphi panel will involves three 'rounds', and for each round you will be asked to answer an online questionnaire that will take approximately 10 - 15 minutes to complete.

The first questionnaire is largely open-ended, to gather ideas from your knowledge and experience. The aim of the second and possible subsequent rounds is to evaluate and re-evaluate ideas and develop consensus among the expert panelists. The concepts identified in the first questionnaire inform the formulation and development of the second questionnaire, with largely close ended questions.

ARE THERE ANY RISKS/INCONVENIENCE?

There are minimal risks as measures are in place to ensure confidentiality and anonymity of your involvement.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part.

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney. If you wish to withdraw from the study after it has started, you can do so at any time without having to give a reason, by contacting [redacted] on [redacted] or [redacted]@student.uts.edu.au

However, if you withdraw from the study after the first or second questionnaire it may not be possible to withdraw your data from the study results if these have already had your identifying details removed.

CONFIDENTIALITY AND CONSENT

By completing this survey you consent to the researcher collecting and using information provided about you for the research project. All this information will be treated confidentially. All data collected will be de-identified, coded numerically and stored securely in UTS facility for use only by this research team, so risk to confidentiality is very low. The research data gathered from this project may be published in a form that does not identify participants in any way and may be used for future research purposes. In all instances your information will be treated confidentially.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact us on the details provided above.

NOTE:
This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

Appendix C

Delphi Round 1 Survey Instrument

Delphi Panel Survey - Innovation in Schools

Indicate your level of agreement with each of the following statements and then comment.

The following are summary statements taken from the literature about innovation in education. Comments are optional however any insights will provide valuable information.

Q1. Innovation is both a process and an outcome (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Q2. Innovation is a process used by educators in response to challenges or changes or to pursue a vision outcome (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Q3. Innovative teaching is both the practice of teaching for creativity and of applying innovation to teaching (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Q4. Innovative teaching involves emerging practices that change what teachers and students do and learn in the classroom (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Q5. Educators are charged with creating an innovative future workforce (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Innovation in schools - your definition.

Please continue the following sentences to share your thoughts and opinions about innovation in schools (*comments are required).

Q6. Innovation in a school context is...

Q7. Innovative teaching is...

Q8. Innovative school leadership is...

Enabling and constraining factors of innovation in schools.

Please comment according to what you have witnessed or experienced in schools (*comments are required).

Q9. *Name some factors that foster innovation in schools (consider micro/ meso/ macro level factors):

Q10. * Name some factors that limit innovation in schools (consider micro / meso / macro level factors):

Factors that impact on innovation in schools.

The items listed below have been identified in literature and social commentary as having a constraining impact on innovation in schools. Please indicate your level of agreement and comment.

**Comments are optional but your insights will provide valuable information and will inform round two of the Delphi study.*

Q11. Prescriptive mandatory curriculum can constrain innovation in schools (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Q12. High stakes, standardised testing can constrain innovation in schools (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Q13. Quality assurance reforms to make teaching practice more consistent, for example teaching standards, can constrain innovation in schools (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Q14. Top-down (system or school) prescriptive teaching programs can constrain innovation in schools (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Q15. Age-based student cohorts can constrain innovation in schools (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Q16. Systems of accountability, such as school inspections, can constrain innovation in schools (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree + comment).

Science, Technology, Engineering and Mathematics (STEM) education in schools

Science, Technology, Engineering and Mathematics (STEM) education in schools

The following final questions (17-19) are in relation to STEM in schools. If applicable to your experience, please comment.

Q17. Do you have experience or expertise in STEM education in schools?

Q18. Do you have experience or expertise in STEM education in K-6 (primary/elementary) education?

Q19. Please comment on any factors that enable or limit innovation in K-6 STEM programs in schools (answer is required):

Thank you

Thank you for your participation. When all responses have been received you will be emailed a summary of the de-identified responses and a link to round two of the Delphi study.

Appendix D

Delphi Round 2 Survey Instrument

Round 2: Delphi Panel Survey - Innovation in Schools

Participant Information and Consent

Thank you for participating as an expert panelist for round two of the Delphi study on innovation in schools.

The second-round survey is different from the first round. There are **no** questions requiring written responses, simply items to rank your level of agreement (although there is facility to make a comment should you wish). The items have been crafted from the written responses in the first round. There are some items from the first survey that need clarification and therefore you are asked to rank these again - you may wish to provide the same ranking as last time.

This survey will take approximately 5 minutes to complete. As with the previous survey, your responses will be confidential and de-identified.

As you will remember, the Delphi study is designed to determine a consensus view and definition of innovation in a school context and has been approved by the University of Technology Sydney (UTS) human research ethics committee (HREC), approval number ETH18-2833. The **participant information sheet** can provide further information if needed**.**

Thank you again for your participation. Your expert insights are most valuable.

PhD candidate
University of Technology Sydney
@student.uts.edu.au

Round 2: Delphi Panel Survey - Innovation in Schools

The following items relate to school leadership. Rate your level of agreement with each.

Innovative school leadership...

Q1. Exhibits professional trust in teachers (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q2. Encourages adaptation and experimentation in teaching practices (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q3. Shapes a culture where mistakes are learning opportunities (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q4. Pushes boundaries, moving away from norm and convention (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q5. Applies a creative mindset (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q6. Is inquisitive (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q7. Aims for improvement (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q8. Is visionary (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q9. Overcomes barriers from system requirements (curriculum, assessment, funding) and 'finds a way' (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q10. Comment (optional):

The following items relate to teaching. Rate your level of agreement with each.

Innovative teaching...

Q11. Involves trying new teaching practices (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q12. Involves engaging with education research (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q13. Involves trying new ways to support technology enhanced learning (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q14. Uses a problem solving or design approach (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q15. Seeks improvement in student learning outcomes (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q16. Allows for learning experiences that promote creative, critical or problem solving thinking (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q17. Comment (optional):

Innovation fostering factors

The following items have been identified as factors that foster innovation in schools. Rate your level of agreement with each of the items below.

Q18. Innovative leadership by the principal (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q19. Teacher autonomy (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q20. A culture of creativity and risk-taking within the school (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q21. A culture of inquiry and exposure to education research and ideas (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q22. Enthusiasm of teachers (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q23. Aptitude and skill of teachers (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q24. Funding for technology (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q25. Funding for professional learning and collaboration (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Q26. Comment (optional):

Innovation Constraining Factors

The following items have been identified as factors that **constrain innovation in schools**. Rate your level of agreement with each of the items below.

Q27. Excessive compliance requirements.

Q28. Insistence on complete consistency in and between teams of teachers.

Q29. Micro-management by leadership within the school.

Q30. Lack of support from leadership (within and/or beyond the school).

Q31. Lack of learning culture within the school.

Q32. Comment (optional):

Indicate your level of agreement with each of the following statements.

You are asked to reconsider the following four items from the round one survey. Comments are optional.

Q33. Educators are charged with creating an innovative future workforce.

Q34. Quality assurance reforms to make teaching practice more consistent, for example teaching standards, can constrain innovation in schools.

Q35. Innovative teaching is both the practice of teaching to build innovation skills in students and of applying innovation to teaching (**this question has been slightly reworded from the round one survey).

Q36. Systems of accountability, such as school inspections, can constrain innovation in schools.

Thank you

Thank you for your participation. When all responses have been received you will be emailed a summary of the de-identified responses and a link to round three of the Delphi study.

Appendix E

Narrative Inquiry Participant Information and Consent Sheet

PARTICIPANT INFORMATION SHEET

HOW DO PRIMARY SCHOOLS CATER FOR INNOVATIVE FUTURES IN STEM?

UTS HREC Approval ETH18-2833

WHO IS DOING THE RESEARCH?

My name is [redacted] and I am a student at UTS. My supervisor is [redacted], Associate Professor, [redacted].

WHAT IS THIS RESEARCH ABOUT?

The aim of this phase of the study is to identify factors that enable and constrain innovation in schools; specifically in the teaching of STEM in K-6 schools. It will do this by conducting interviews with stakeholders at schools that have implemented innovative STEM programs. The methodology used for the study is Narrative Inquiry, which is a qualitative research method that takes the recollections and stories of participants and forms them into a narrative about the innovative teaching of STEM in K-6 schools.

WHY HAVE I BEEN ASKED?

You have been invited to participate in this study because you have been identified as being involved with an innovative STEM program in your school.

Your contact details were obtained by/from [redacted].

IF I SAY YES, WHAT WILL IT INVOLVE?

If you decide to participate, I will invite you to take part in a semi-structured interview.

ARE THERE ANY RISKS/INCONVENIENCE?

There are minimal risks as measures are in place to ensure confidentiality and anonymity of your involvement. I will ask permission to audio record the interview so this may cause minor discomfort if you are self-conscious, however I will take measures to put you at ease and will not record if you would not like me to.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part.

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney. If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason, by contacting [redacted] on [redacted] or [redacted]@student.uts.edu.au. If you withdraw your interview and transcript will be deleted.

CONFIDENTIALITY

By signing the consent form you consent to the research team collecting and using personal information about you for the research project. All this information will be treated confidentially. Your responses and data will be de-identified and pseudonyms will be used. All information will be kept on secure storage accessible only to the researcher. Your information will only be used for the purpose of this research project.

We would like to store your information for future use in research projects that are an extension of this research project. In all instances your information will be treated confidentially.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact us on the details provided above. You will be given a copy of this form to keep.

NOTE:

This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 [redacted] or email: [redacted]@uts.edu.au], and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

Appendix F

Narrative Inquiry –Semi Structured Interview Schedule

Initiation:

As you know, the topic of my research is innovative teaching and leadership of STEM in K-6 schools. I am seeking to find out the factors that enable and constrain innovation in STEM education K-6.

I will then position myself within the research, tell my brief 'story'

I am interested in hearing about your experiences with your STEM program.

The structure of the interview will firstly involve your uninterrupted telling of your story. Then we will take some time for me to ask some clarifying questions about what you have told me. The interview should take approximately twenty minutes to half an hour. You can withdraw from the interview at any time and we can take breaks if needed during this time.

Main Narration:

Please tell me about STEM in your school…

When the narration starts, it must not be interrupted until there is a clear 'coda', meaning that the interviewee pauses and signals the end of the story. During the narration, I will restrict myself to active listening, non-verbal or paralinguistic support and showing interest ('Hmm, 'yes', 'I see'). While listening I will develop in mind and/or on paper, the questions for the next phase of the interview.

When the participant marks the 'coda' at the end of the story, I will probe for anything else: 'is this all you want to tell me?' or 'is there anything else you want to say?'

Questioning:

Questions refer both to events mentioned in the story and to topics of the research project.

I will not ask why-questions; only questions concerning events like 'what happened before/after/then?'

Questions can elicit information about 'moral tales', 'success stories' and 'epiphanies'

I will not ask about opinions, attitudes or causes as this invites justifications and rationalisations.

Concluding Talk

At the end of the interview, informal talk can throw light on the more formal accounts given during the narration. This is contextual information that can assist in the interpretation of data. Why-questions can be used. A summary of the contents of the small-talk will be completed immediately after the interview.

Appendix G

Researcher Journal Entry

[illegible]

Interviewed [redacted] via zoom. Interesting when compared to [redacted] account. Both feel that they initiated the program – when looking at the different aspects that they handled both are correct. Will ~~be~~ need to be communicated sensitively while remaining true to the story. Will check with them both upon writing – make sure accurate.

Very interesting that both raised the issue of the other staff at the school. Both seem to have reflected heavily on the fact that the others weren't heavily involved or enthusiastic. Will have to check previous work on engagement of STEM teaching & engaging reluctant teachers to STEM. follow up.

Appendix H

Ethics Approval

Your ethics application has been approved as low risk - ETH18-2833

research.ethics@uts.edu.au <research.ethics@uts.edu.au>

Fri 11/01/2019 2:13 PM

To: [redacted]

Cc: [redacted]

Dear Applicant

Your local research office has reviewed your application titled, "How do primary schools cater for innovative futures in STEM?", and agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application, subject to any conditions detailed in this document.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy (http://www.gsu.uts.edu.au/P.olicies/research-management-P-olicY..html).

Your approval number is UTS HREC REF NO. ETH18-2833.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.

The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat (Research.Ethics@uts.edu.au).

The Principal Investigator will notify the UTS HREC of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions can be found at httP-s://staff.uts.edu.au/to P-i_ chub/Pages/Researehing/Resea reh%20Ethics%20and%20Integrity/Human %20research%20ethics/Post-aP-P-roval/P.ost-aP-.P-.roval.asP-x#tab2.

The Principal Investigator will promptly report adverse events to the Ethics Secretariat (Research.Ethics@uts.edu.au). An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.

The Principal Investigator will report to the UTS HREC annually and notify the HREC when the project is completed at all sites. The Principal Investigator will notify the UTS HREC of any plan to extend the duration of the project past the approval period listed above through the progress report.

The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).

The Principal Investigator will notify the UTS HREC of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

Appendix I

SERAP

Education
Public Schools

Ms Rosemary Di Mattia
[redacted]

DOC20/728399
SERAP 2019011

Dear Ms Di Mattia

I refer to your application to conduct a research project in NSW government schools entitled *How do primary schools cater for innovative futures in STEM?* I am pleased to inform you that your application has been approved.

You may contact principals of the nominated schools to seek their participation. **You should include a copy of this letter with the documents you send to principals.**

This approval will remain valid until 30 July 2021.

The following researchers or research assistants have fulfilled the Working with Children screening requirements to interact with or observe children for the purposes of this research for the period indicated:

Researcher name	WWCC	WWCC expires
Rosemary Di Mattia	[redacted]E	[redacted]

I draw your attention to the following requirements for all researchers in NSW government schools:

- The privacy of participants is to be protected as per the NSW Privacy and Personal Information Protection Act 1998.
- School principals have the right to withdraw the school from the study at any time. The approval of the principal for the specific method of gathering information must also be sought.
- The privacy of the school and the students is to be protected.
- The participation of teachers and students must be voluntary and must be at the school's convenience.
- Any proposal to publish the outcomes of the study should be discussed with the research approvals officer before publication proceeds.
- All conditions attached to the approval must be complied with.

When your study is completed please email your report to: serap@det.nsw.edu.au.
You may also be asked to present on the findings of your research.

I wish you every success with your research.

Yours sincerely

Production Note:
Signature removed
prior to publication.

Dr Robert Stevens
Manager, Research
Strategic Analysis | CESE
30 July 2020

STRATEGIC ANALYSIS UNIT | CESE
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