Rural school STEM success:
Practices contributing to high STEM performance in rural Victorian government secondary schools

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Certificate of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma at Charles Sturt University or any other educational institution, except where due acknowledgment is made in the thesis. Any contribution made to the research by colleagues with whom I have worked at Charles Sturt University or elsewhere during my candidature is fully acknowledged.

I agree that this thesis be accessible for the purpose of study and research in accordance with the normal conditions established by the Executive Director, Division of Library Services or nominee, for the care, loan and reproduction of theses.

This thesis does not exceed 100 000 words.

Signed: Steve Murphy
Acknowledgement of Assistance

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This research was supported by an Australian Government Research Training Program (RTP) Scholarship.
Publications resulting from the research

To date, eleven publications have resulted from the research presented in this thesis. These are listed below. Three of these publications are co-authored and statements from co-authors confirming the authorship contribution of the PhD candidate for each of these papers is included after the list of publications. This thesis includes excerpts from two of these co-authored publications. In these cases, the statement from co-authors also includes an agreement that excerpts from these papers can be included and submitted for examination.


**Murphy, S.** (2020). Motivating rural students in STEM: Practices contributing to student engagement with STEM in rural Victorian schools. In A. MacDonald, L. Danaia, & S.
Murphy (Eds), *STEM education across the learning continuum: Early childhood to senior secondary* (pp. 293-311). Springer.


**Murphy, S.** (2020). Achieving STEM education success against the odds. *Curriculum Perspectives.* https://doi.org/10.1007/s41297-020-00110-8


Statement from Co-Authors: Confirming the Authorship Contribution of the PhD Candidate


As author of the above named paper, I confirm that the PhD candidate made the following contributions:

- Conceptualisation of the paper;
- Review and interpretation of the literature; and
- Writing, editing, and revision of the manuscript.

Furthermore, I agree to the inclusion of excerpts from this paper in this doctoral research submitted for examination.

2 October 2019
Steve Murphy
Date

13 February 2020
Amy MacDonald
Date

13 February 2020
Lena Danaia
Date

5 October 2019
Audrey (Cen) Wang
Date
Statement from Co-Authors: Confirming the Authorship Contribution of the PhD Candidate


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2 October 2019
Steve Murphy
Date

13 February 2020
Amy MacDonald
Date

13 February 2020
Lena Danaia
Date
Definitions of key terms

There are a range of key terms used throughout this thesis that are sometimes ill defined or used in varying ways in the wider literature. To clarify their use in this thesis the following definitions are offered:

- **Academic emotions**: Emotions experienced by students in learning contexts that influence their effort, persistence, and selection of strategies for learning.
- **Educator**: A professional working in an educational setting who contributes to the education of a student. This can include teachers, school leaders, and education support personnel.
- **Learning environment**: The physical, social and cultural context in which learning takes place.
- **Learning journey**: Students’ cumulative educational experiences from early childhood through to secondary school.
- **Motivational beliefs**: The perceptions an individual has about the value of a task and their expectation of success in that task.
- **Non-metropolitan schools**: Schools located in regional or remote areas, including in regional cities but not in capital cities.
- **Rural schools**: Schools located in regional or remote areas, but not those located in regional cities.
- **STEM**: Any human activity or product that involves the knowledge and processes of Science, Technology, Engineering, and/or Mathematics.
- **STEM education**: Any teaching and learning experiences that build students’ interest, knowledge and/or skills in STEM, or any of its component disciplines. As such, it may encompass elements of traditional Science, Technology, Engineering and Mathematics lessons, integrated studies, special events, excursions, extension programs, and school coordinated after-school enrichment programs.
- **STEM program**: The science, technology, engineering and mathematics subjects and activities of a school.
- **STEM subject**: Any regularly timetabled program of learning delivered by a school that is designed to cover content from one or more of the STEM disciplines.
- **STEM team**: The team of educators responsible for planning and implementing all STEM education activities at a school.
Abstract

STEM (an acronym generated from the disciplines of Science, Technology, Engineering, and Mathematics) education is viewed internationally as essential for preparing a workforce and a citizenry able to ensure a safe, healthy, sustainable, and economically prosperous future. Australia, similar to other English speaking Western nations, is particularly focused on improving STEM education given its decreasing participation rates in further STEM study and STEM careers, and a relative decline in school STEM achievement. Most Australian jurisdictions have released STEM education policies in recent years, advocating for an array of STEM education practices with varying levels of support from research. The performance of Australian students in rural schools in STEM is well behind that of their metropolitan counterparts, suggesting the need to improve STEM education is particularly important in rural schools. Unfortunately, there are few strategies aiming to address this in Australian STEM education policies, and research evidence about STEM education in rural schools is scant, particularly in Australian contexts.

This study sought to address this deficit by first investigating the relative success of rural Victorian secondary schools in STEM education, and then by studying the STEM education practices of the schools with relatively high participation and achievement in senior STEM subjects. The relative success of rural schools was investigated in Phase One of this study through the analysis of secondary data collected by the Victorian Department of Education and Training (DET), including school location, socio-economic status (SES), and mean school enrolment and achievement in senior STEM subjects, in 2014, 2015 and 2016. This analysis demonstrated that rural school success in STEM subject enrolment and achievement varied, and also allowed the identification of relatively high STEM performing rural Victorian government secondary schools. Case studies were conducted of four of these schools in Phase Two of this study. Data were collected through site visits, interviews with principals and STEM teachers, group interviews with senior students, and sampling school documents. Thematic analysis of the data from each school identified practices that contributed to each school’s STEM success, as well as factors that facilitated these practices. Multi-case synthesis identified practice themes common across the four sites, as well as highlighting differences. Finally, the practices that comprised effective STEM education in these rural schools were compared to those factors proposed to contribute to effective STEM education by researchers, and by Australian STEM education strategies.
While Phase One of this study demonstrated that rural Victorian schools do tend to underperform in STEM, aligning with many previous studies, it identified 19 relatively high STEM performing rural schools, showing that rural schools can succeed in STEM education. Phase Two showed that, at the four rural schools which were the subjects of case study, this STEM success was associated with a bundles of practices, rather than any particular program or intervention. These practice bundles were facilitated by each school’s location and strong relationships within and beyond the schools. Some of the practices contributing to STEM success aligned with those promoted by STEM literature and policy, including those that develop student STEM engagement, facilitate STEM learning throughout schooling, and build the capacity of STEM teachers. Other practices found to contribute to rural school success are far less prominent in STEM education literature, including place-based learning, differentiated instruction, and maintaining high expectations for STEM learning with support. Finally, some conspicuous STEM education themes in the literature were almost absent from the participant accounts of school STEM success in this research, including the integration of STEM disciplines, the use of inquiry learning, the use of digital technologies, STEM education delivered through school partnerships with industry or community organisations, and directly addressing equity issues in STEM.

These findings suggest that rural schools can best facilitate STEM education by capitalising upon their local environment and resources to deliver STEM learning experiences that are hands-on, real-world, and connected to their students’ lives. Rural schools can also use the strong relationships that typically exist within and beyond these small, community-based schools to set high expectations, and effectively support all students to meet these expectations. They should adopt creative approaches, including unconventional timetabling, to ensuring a diversity of STEM pathways are maintained for their students. Finally, to achieve all this, rural schools must build autonomous teams of STEM teachers who drive their own professional learning to best meet the needs of their students.

The findings of this study suggest a misalignment between recommendations in Australian STEM strategies, and practices that can contribute to STEM education success in rural schools, challenging policy makers to more carefully consider the practices best suited to rural schools’ contexts, opportunities, and constraints. These findings also have implications for educational researchers. Rural STEM education has received limited research attention, hence, this study makes a contribution to building the evidence base regarding effective STEM education practice in rural schools. This study also identifies three under-researched practices capable of contributing to the rural schools’ STEM success – high
expectations with support, differentiated instruction, and place-based learning. Further, the study offers proof of concept of a mechanism for expanding our understanding of effective STEM education in particular contexts such as rural schools, through seeking out school success in these contexts and then investigating the practices that have led to this success.
Chapter 1: Introduction

1.1 Preamble
This introductory chapter builds the case for the significance of this study. The significance of this study is established by first considering the social, political, economic, and educational value of STEM education. The lack of consensus around effective STEM education amongst policy makers, educators, and researchers is considered, establishing a need for more research in this area. Australia’s current relatively poor student participation, engagement, and achievement in STEM are outlined, as is the even poorer performance of Australian students in rural schools, before identifying there is limited research into effective STEM education in rural schools, let alone Australian rural schools. This establishes the impetus for research into effective STEM education in rural schools, such as the research completed in this study.

This chapter then provides a brief overview of the mixed-method design of the study and identifies the three research questions guiding the work. The use of five potentially problematic terms used throughout this thesis is clarified: “STEM education”, “learning journey”, “STEM subject”, “non-metropolitan”, and “rural”. Finally, an outline of the structure of this thesis is provided.

1.2 The importance of STEM education
The STEM acronym (standing for Science, Technology, Engineering, and Mathematics) was coined in the late 1990s in the US by the National Science Foundation, after a brief dalliance with the less graceful ‘SMET’ (Sanders, 2009). Since then, STEM has been variously used to label a wide variety of things associated with Science, Technology, Engineering, and Mathematics such as industries, careers, research, community initiatives, and education programs. What STEM is and should be is contested on multiple fronts (Breiner, Harkness, Johnson, & Koehler, 2012). Despite a lack of an agreed definition, STEM has become a focus for industry, lobbyists, and policy makers, particularly in Western nations, with the release of many key statements and position papers on the importance of STEM (e.g., Australian Office of the Chief Scientist, 2013; Council of Canadian Academies, 2015; European Centre for the Development of Vocational Training, 2014; House of Commons Science and Technology Committee, 2017). Shanahan, Burke and Francis (2016) advocate viewing STEM as a ‘boundary object’. Boundary objects have flexible definitions and exist where different groups with varied interests and understandings are working together. Taking Shanahan,
Burke and Francis’ lead, this thesis uses a broad definition of STEM. STEM is viewed here as encompassing any human activity or product that involves the knowledge and processes of Science, Technology, Engineering, and/or Mathematics.

While the term STEM may be used in many different ways, there is greater agreement on the importance of STEM. Internationally, there is an increasing trend to view STEM as essential for addressing an array of local, national, and global problems (Gough, 2015). In Australia, the Office of the Chief Scientist (2013) described STEM as key to addressing “the five most significant societal challenges that we presently face…:"
  - Living in a changing environment
  - Promoting population health and wellbeing
  - Managing our food and water assets
  - Securing Australia’s place in a changing world
  - Lifting productivity and economic growth.” (p. 5)

Concomitant with the increased focus on STEM, has been an international focus on the importance of STEM education. The United States federal STEM education strategic plan argues that STEM education is essential to ensure “the health and longevity of our Nation’s, citizenry, economy and environmental resources” (National Science and Technology Council, 2013, p. 3). The United Kingdom positions STEM education as a mechanism for both economic growth and for providing citizens with the STEM literacy necessary to engage in important debate and decision making (HM Treasury, 2011). The African Union sees STEM education as having an important role in creating a diverse and industrialised economy, protecting the environment, responding to climate change, and improving population health (Tilkly et al., 2018). The United Nation’s Incheon Declaration for Education 2030 recommends the strengthening of STEM education as a key strategy for meeting its sustainable development goals (UNESCO, 2015). Fensham (2008), in his report to UNESCO, suggests that “the quality of school education in science and technology has never before been of such critical importance to governments” (p. 4). He argues quality science and technology education is essential for socially and environmentally sustainable development by ensuring the supply of scientifically and technologically skilled professionals to drive it, and the preparation of a scientifically and technologically informed citizenry to guide it. Zollman (2012) suggests the need for improved STEM education is also driven by a personal imperative, in addition to the social, economic, and environmental demands,
suggesting it is essential for our “personal needs to become … fulfilled, productive, knowledgeable citizen[s]” (p. 12).

Despite this fairly holistic justification for the importance of STEM, the STEM agenda is often regarded as being driven by narrower economic goals (Williams, 2011). In Western nations, STEM advocacy is part of a push to increase the STEM skills of workforces and to improve international economic competitiveness. The European Commission said, “STEM skills are critical to innovation and in creating a competitive edge in knowledge-intensive economies” (European Centre for the Development of Vocational Training [CEDEFOP], 2014, p. 1). The Council of Canadian Academies state, “We are convinced that high-quality investments in STEM skills — in both early education and in more advanced training — are critical to Canada’s prosperity” (Council of Canadian Academies, 2015, p. vii). The STEM agenda in Australia could be seen as significantly motivated by similar economic aims. The Australian Industry Group has been advocating for a national emphasis on STEM to strengthen the Australian economy for several years (Australian Industry Group [AIG], 2013, 2015, 2017). The National Innovation and Science Agenda positions improvements in STEM education as a mechanism for ensuring Australia is economically prosperous and living standards remain high (Department of the Prime Minister and Cabinet, 2015). Australia’s current Chief Scientist, Alan Finkel, suggests that STEM education and training can lead to “a STEM–powered economy” (Office of the Chief Scientist, 2016, p. iii).

While it can be argued that the STEM education agenda was to some degree imposed upon educators (Blackley & Howell, 2015), increasingly educators are valuing STEM education as presenting an opportunity for positive change in education. The significant support that STEM education has attracted from governments, industry, and the wider community provides an unusual opportunity to develop teaching and learning of STEM (Shanahan et al., 2016). Myers and Berkowicz (2015) go further, heralding STEM education as providing “a vehicle to free educators from 19th and 20th century thinking, morphing how we have structured schools, teaching and learning” (p. 7). They see the STEM education movement as having such potential due to unprecedented wide spread support from across the community. STEM education challenges educators, from early childhood to tertiary sectors, to re-envision the structures and modes of education. As such, Myers and Berkowicz anticipate STEM education will trigger system-wide transformation as the new practices STEM education demands cannot be accommodated without impacting on all school subjects and practices.
1.3 Views of STEM education

Despite widespread support for STEM education, the meaning of STEM education varies, and is often dependent on the stakeholder using the term (Breiner et al., 2012). STEM education as a term only became popular recently, in the late 2000s, to refer to a broad range of education activities including both formal and informal education programs in either preschool, primary, secondary, tertiary or community settings (Shanahan et al., 2016). STEM education has been used as a label for a plethora of items, initiatives, and programs, including commercial educational resources, conferences, workshops, curriculum materials, websites, education department initiatives, visiting educator programs, and excursions (Bybee, 2013). Given its relatively recent appearance, and its broad application by a diversity of stakeholders, it is unsurprising that there is currently limited agreement about what constitutes STEM education.

Amongst policy makers internationally, there is general agreement as to the aims of STEM education, but not how to achieve these aims. Many national STEM education strategies aim to develop student capabilities and interest in the STEM disciplines, ultimately leading to increased participation and achievement in further STEM study and careers (Coggins et al., 2010; Education Council, 2015; National Science and Technology Council, 2013; The Parliamentary Office of Science and Technology, 2013). Many also aim to increase the participation and achievement of groups under-represented in STEM, particularly females, Indigenous students, or students from lower socio-economic backgrounds. While they share similar aims, policy makers do not demonstrate the same level of agreement as to how to achieve these aims. For example, a study that I led of the various Australian jurisdictional STEM education strategies (Murphy, MacDonald, Danaia, & Wang, 2019; see Appendix B) revealed little uniformity in the strategies’ positions on integration of the STEM disciplines, the importance of student affect in STEM, the role of digital technologies, or the part STEM education should play throughout a child’s schooling.

While there is better agreement amongst educational researchers, even they do not hold a common understanding of the elements of STEM education. There is some agreement that STEM education is integrated, and explores real-world contexts by employing inquiry learning approaches (Asunda & Mativo, 2015; Bybee, 2013; Honey et al., 2014; Lowrie et al., 2018). However, the form of integration is contested, with researchers debating the merits of multidisciplinary, interdisciplinary, or transdisciplinary approaches (Kelley, 2010), or content versus context integration (Moore, 2014), or advocating for pragmatic approaches more easily implemented in schools (Bybee, 2013; Williams, 2011). Similarly, there are a
broad range of practices that fall under the umbrella of inquiry learning (Fitzgerald, et al., 2019; Gee & Wong, 2012), and the impact of these practices appear to vary with the gender, ethnicity, and socio-economic status of students, and even the country in which the practices were implemented (Gee & Wong, 2012; Von Secker, 2002).

One area of general agreement amongst policy makers, researchers and educators, is that STEM engagement and capabilities are developed throughout a learner’s life time. Lobby groups call for improved STEM education across the school sectors (e.g. AIG, 2015; Council of Canadian Academies, 2015). STEM education policy highlights the need for effective STEM education in early childhood, compulsory schooling, and beyond (Murphy, MacDonald, Danaia, & Wang, 2019). There is also sound research evidence that students’ experiences in STEM education in all stages of learning contribute to the development of their engagement (e.g. Archer et al., 2013; Ardito et al., 2014; Larkin & Jorgensen, 2016) and capabilities (e.g. Bagiati & Evangelou, 2016; Zoller 2011) in STEM subjects. Given that an individuals’ accrued education experiences are widely agreed to contribute to their STEM capabilities, the term “learning journey” has been used in this thesis to describe these cumulative educational experiences from early childhood through to secondary school. Despite wide agreement about the importance a student’s learning journey in STEM education, there has been limited exploration of the contribution of factors believed to contribute to effective STEM education across the learning journey. The majority of STEM education research projects focus on short term interventions implemented at the classroom level (e.g., English et al., 2017; Molina, et al., 2016; Nemiro et al., 2017; Yanyan et al., 2016), with limited research into whole school approaches to STEM education (e.g., Hefty, 2015). In contrast, this study considers the contribution of students’ learning journey throughout secondary school, in some cases including upper primary school, to their engagement and achievement in STEM education.

This study does not presuppose any particular form for STEM education. Instead it seeks out schools that are apparently successful in STEM education (by virtue of their relatively high enrolments and achievements in senior Science, Technology, Engineering or Mathematics subjects) independent of the shape of their education programs. Given this, a broad notion of STEM education is entertained, one that includes any programs that build students’ interest, knowledge, and/or skills in STEM or any of its component disciplines. As such, it may encompass traditional subjects dealing separately with Science, Technology, Engineering or Mathematics, integrated studies, special events, excursions, enrichment programs, and school coordinated afterschool enrichment programs. Once high STEM
performing schools are identified, the study then seeks to identify the elements that have contributed to effective STEM education in their particular contexts. This provides the opportunity to compare the aspects of STEM education at the schools studied to those promoted, by policy makers and researchers, as contributing to effective STEM education, testing the validity of these notions of effective STEM education in rural Australian contexts.

1.4 STEM education in Australia
In Australia, along with many other nations, the perceived underperformance of contemporary modes of mathematics, science, technology, and engineering education adds additional impetus to the STEM education movement. Concerns are raised about participation and engagement, as well as achievement in STEM education (Marginson et al., 2013). These concerns are shared by other English speaking Western Countries, including the USA and the UK (Blackley & Howell, 2015).

1.4.1 Participation and Engagement
The proportion of Australian students choosing to study science and mathematics in senior secondary school have declined since 1994 (Office of the Chief Scientist). Other than entry level mathematics and earth sciences, the participation rates in all mathematics and science subjects are lower than they were in the early 1990s (Kennedy et al., 2014; Office of the Chief Scientist, 2017). There has also been a decline in the participation rates in digital technology subjects since 2000 (Kennedy et al., 2018a). In Australia, the declining participation rates in senior secondary advanced mathematics, chemistry, and physics are seen as particularly concerning (Education Council, 2018; Goodrum et al., 2012; McPhan et al., 2008; Timms et al., 2018). There are similar concerns expressed about senior school STEM participation rates in other nations, including the US and the UK (House of Commons Science and Technology Committee, 2017; Marginson et al., 2013; National Science and Technology Council, 2013).

It is recognised that issues in senior school participation are associated with declines in STEM engagement and STEM aspirations much earlier in students’ learning journeys (Jeffries et al., 2019). Trends in International Mathematics and Science Study (TIMMS) data suggest that in Australia, as well as internationally, there is a decline from Year 4 to Year 8 in the proportion of students reporting they like science or mathematics, and an increase in the proportion of students reporting they do not like learning these subjects (Thomson, Wernert et al., 2017). van Tuijl and van der Molen (2016) in their review of the international literature
in this area suggest that students in Western countries have a largely positive view of STEM up until age 10, but that many have changed this view by age 12. There is evidence that Australian students’ attitudes towards STEM tend to decline during the beginning of secondary school, and that these attitudes impact their intention to study STEM subjects in later years (Kennedy et al., 2018b). It is likely that negative attitudes towards mathematics in particular become well-formed for some students during the early years of primary school (Larkin & Jorgensen, 2016). Consequently, STEM education in Australia, as well as in other western nations, is called upon to improve student engagement in STEM throughout schooling (CEDEFOP, 2014; Education Council, 2015; House of Commons Science and Technology Committee, 2017).

1.4.2 Achievement
In many countries, including Australia, declining STEM participation is concomitant with declining STEM achievement. Programme for International Students Assessment (PISA) results show that mathematics literacy declined in 13 nations and improved in only 9 from 2003 to 2015 (Thomson, De Bortoli, & Underwood, 2017). In most countries, science achievement has not improved from 2006 to 2015 (OECD, 2018). In Australia, student performance in mathematics, science, and digital technologies has either stagnated or declined across most year levels of schooling (Timms et al., 2018). The mathematics and scientific literacy of Australian Year 9 students has declined both relative to other nations and in absolute terms (Thomson, De Bortoli, & Underwood, 2017). TIMSS data show that though Australian Year 4 mathematics achievement improved from 2003 to 2007 it has not changed significantly since then, and that Year 8 achievement has not changed significantly since 1995 (Thomson, Wernert, et al., 2017). In science, there has been little change in Year 4 or Year 8 achievement since 1995. Australia’s National Assessment Program (NAP) similarly suggests that numeracy and scientific literacy achievement have stagnated (Australian Curriculum Assessment and Reporting Authority [ACARA], 2017a; Connolly, 2017a). NAP testing of ICT literacy suggests no significant change in Year 6 performance since 2005, but a decline in the average performance of Year 10 students (ACARA, 2018). Australia’s current performance in these areas further fuels the push to improve STEM education.

1.4.3 Equity
Beyond concerns about the average participation and achievement levels in STEM, there are significant equity issues associated with contemporary STEM education. There are demands
internationally to redress the under-representation of females studying STEM in senior secondary and tertiary levels, and aspiring to STEM careers (UNESCO, 2017). On average, students from low socio-economic backgrounds underperform in science (OECD, 2018), mathematics (Grootenboer & Hemmings, 2007; Kalaycioglu, 2015; Mullis et al., 2015; OECD, 2018) and technology (National Assessment of Educational Progress, 2014), and are less likely to pursue further study in STEM; (House of Commons Science and Technology Committee, 2017). There are also concerns about the participation and achievement of students from different cultural backgrounds, particularly Indigenous backgrounds, in many countries (Council of Canadian Academies, 2015; National Science and Technology Council, 2013). The motivation to address these equity issues in STEM is presented both as a need to address an injustice (e.g., National Science and Technology Council, 2013), as well as an opportunity to improve the diversity of the talent pool available to STEM industries (e.g., Council of Canadian Academies, 2015).

STEM education in Australia confronts a similar set of inequities. While female students achieve results comparable to males in numeracy (ACARA, 2017a), and out-perform males in scientific literacy (Connolly, 2017a) and ICT literacy (ACARA 2018), their participation is lower in all senior secondary STEM subjects, apart from Biology, entry-level Mathematics, and Food Technology (Kennedy et al., 2014; Kennedy et al., 2018a). Australian students identifying as Aboriginal or Torres Strait Islanders, underperform non-Indigenous students by approximately two and a half years of schooling in science, and two and a third years of schooling in mathematics (Thomson, De Bortoli, & Underwood, 2017). Similarly, Year 9 students from low socioeconomic backgrounds achieve lower results in mathematical and scientific literacy than students from wealthier backgrounds (Thomson, De Bortoli, & Underwood, 2017). This pattern of achievement was also reflected in my research into the results of Victorian Certificate of Education (VCE) for Science (Murphy, 2018a), Technology (Murphy, 2019a), and Mathematics (Murphy, 2019b). Further, I found that students from the highest socioeconomic backgrounds were more likely to enrol in VCE Mathematical Methods, Specialist Mathematics (Murphy, 2019b), Physics, and Chemistry (Murphy, 2018a), that those from lower socioeconomic backgrounds. Another study found that, in general, the higher a student’s socioeconomic status, the more likely they are to be enrolled in a science subject (Cooper et al., 2018).
1.5 STEM education in rural Australia

STEM education in Australia also has equity issues associated with rurality. International and national testing show non-metropolitan students are significantly behind their metropolitan counterparts in STEM in Australia. The 2015 PISA tests suggested that metropolitan students were around 12 to 18 months ahead of rural students in both mathematical and scientific literacy (Thomson, De Bortoli, & Underwood, 2017). Even more concerning is that trend data reveals that the gap between metropolitan and rural students’ scientific and mathematical literacy is widening. Similar disparities can be seen in the results of the 2015 TIMSS (Thomson, Wernert, et al., 2017), the NAPLAN (ACARA, 2017a), and NAP testing in science (Connolly, 2017a) and Information and Communication Technology (ICT) (ACARA, 2018). In line with these findings, my research revealed that non-metropolitan students also achieved lower results than metropolitan students in Year 12 VCE science (Murphy, 2018a) and mathematics (Murphy, 2019b) subjects.

This gap between the STEM performance of metropolitan and rural schools is of significant concern. Nearly a third of Australian students, over 1 million students, attended schools outside major cities (Australian Bureau of Statistics, 2017). Achievement in mathematics and science is often used to determine access to a range of tertiary education opportunities (Victorian Tertiary Admissions Centre, 2016). The shift to a knowledge-based economy means young people from rural and remote areas need tertiary qualifications generally to access employment opportunities into the future (CESE, 2013). This demand for tertiary education is exacerbated by the growth in STEM careers and the concurrent shrinking of less skilled career opportunities (Australian Industry Group, 2015). Consequently, the relative poor performance of rural students in school STEM subjects is likely to result in more limited access to tertiary education and to career growth areas. Beyond the impact of poor school STEM performance on individual students is the impact on rural communities, with rural communities raising a generally less STEM literate workforce. Further, given the documented difficulties attracting and retaining professionals, including those in STEM industries such as computing, engineering, and medicine (Miles et al., 2006; Viscomi et al., 2013) it seems rural communities will have difficulties making up for this by importing a STEM literate workforce. Given this, poor rural school STEM performance also impacts Australia as a whole. The rural workforce plays a pivotal role in producing our food, collecting our water, generating our power, managing our resources, and protecting our environment - all of which increasingly require STEM skills to do efficiently, competitively and sustainably. Rural areas are a major contributor to Australia’s economy, with 67% of the
value of Australia’s exports, including those from STEM driven industries such as mining, agriculture, forestry, and fossil fuel production, coming from rural communities (National Rural Health Alliance, 2015). The deficit in rural school STEM performance must be addressed in the interest of individual students, rural communities, and Australia as a whole.

1.6 Research in rural STEM education
As will be discussed in the next chapter, published research about rural STEM education is relatively scant, particularly in Australian contexts. While the deficit in rural STEM education performance is fairly well described, the factors contributing to this deficit have not been comprehensively explored. Rural schools’ lower performance in science and mathematics has been associated with poorer access to senior science and mathematics subjects (Lyons et al., 2006; McPhan et al., 2008), difficulties recruiting and retaining science and mathematics teachers (Handal et al., 2013; Weldon, 2016), lower learning expectations in mathematics (Pegg & Panizzon, 2011), and limited access to science, mathematics, and ICT learning resources (Lyons et al., 2006), however the evidence base to support these findings is not extensive. Even less well researched are factors that contribute to STEM success in rural schools. Here, there has been minimal research in Australian contexts, other than perhaps research into effective mathematics teacher development in rural contexts (e.g., Goos et al., 2011; Jorgensen, 2016a).

1.7 Aims and design of the study
One of the five areas for national action in the Australian National STEM School Education Strategy is to build a strong evidence base that develops our understanding of effective STEM education in Australian contexts (Education Council, 2015). Of all the contexts, it is arguable that researchers should prioritise investigating STEM education in rural Australian schools, where school STEM performance is amongst the poorest, where the evidence base around effective STEM practice is some of the thinnest, and where the benefits, at the individual, community, and national level, are potentially greatest.

This study aimed to contribute to Australia’s understanding of effective STEM education in rural schools. It did so without pre-supposing a particular form or approach to STEM education, and takes a whole-of-school view of STEM education, regarding STEM success as contributed to throughout schooling. It searched for secondary schools achieving success in terms of participation and achievement in senior STEM education, and then
examined practices across the school, and the factors enabling these practices, that led to STEM education success at these schools. Two phases of research were required to achieve this. Phase One was a quantitative investigation of senior school data routinely collected by the Department of Education and Training Victoria (DET). This phase resulted in the development and validation of criteria for identifying “school STEM success”, which were then employed to identify schools performing better than expected in STEM, given their location and socioeconomic background. Phase Two was a multi-case study investigation of four of the relatively high STEM performing schools identified in Phase One. This involved the collection of data through school visits, interviews with teachers and principals, group interviews with students, and acquisition of school documents and policies. These data were subject to thematic analysis to determine which practices had contributed to each school’s STEM success, and which factors enabled these practices. Finally, Phase Two involved a multi-case synthesis of practices and enabling factors contributing to rural school STEM success, and an analysis of these practices compared to practices promoted in both the literature, and in Australian education policy, as contributing to effective STEM education.

Together, Phase One and Phase Two answer the three research questions guiding this study:

1. Which rural Victorian government schools achieve relative success in STEM education?
2. What practices are believed to have contributed to the success of high STEM performing rural Victorian government schools?
3. To what extent do the practices of high STEM performing rural schools reflect the factors proposed in the literature as contributing to school STEM success?

1.8 Definitions

Five relatively amorphous terms, “STEM education”, “learning journey”, “STEM subjects”, “non-metropolitan”, and “rural” are used throughout this thesis. The meanings intended in this thesis for these are deliberately broad. As already discussed, STEM education is used to refer to any teaching and learning experiences delivered or accessed by the schools in this study that built students’ interest, knowledge and/or skills in STEM, or any of its component disciplines. As such, it may encompass elements of traditional Science, Technology, Engineering and Mathematics lessons, integrated studies, special events, excursions, extension programs, and school coordinated after-school enrichment programs. Also, as
discussed above, STEM education impacts upon children from early childhood, through the primary and secondary school years, and beyond. In this thesis, these experiences from early childhood through to the completion of secondary school are referred to as a student’s learning journey.

The term STEM subject is used to refer to any regularly timetabled program of learning delivered by a school that was designed to cover content from one or more of the STEM disciplines. So STEM subjects include truly integrated STEM subjects, as well as more conventional mathematics, science, technology, and engineering subjects. In Victoria, where this study took place, science includes Biology, Chemistry, Environmental Science, Physics, and Psychology (VCAA, 2017). Psychology is sometimes associated with the social sciences (Office of the Chief Scientist, 2013) so its status as a STEM subject may be questioned. However, as the VCE Psychology subject shares primary aims with the other science subjects including: to develop students’ skills in, and knowledge of, scientific investigation through both field and laboratory experimentation and inquiry; to develop students’ understandings of local and global science-based issues; and to develop students’ ability to apply their scientific understandings and skills in personal, social, environmental contexts (VCAA, 2016), it has been included as a STEM subject for the purpose of this study.

Technology subjects include both digital technologies, such as computing and software development, and design technologies, such as design and food technology. These subjects are discussed in further detail in Chapter 4, Section 4.3. These broad definitions for STEM education and STEM subjects are adopted to avoid presupposing practices that may have contributed to the success of the schools in this study.

An equally broad definition is adopted for the use of the terms non-metropolitan and rural. The Australian Bureau of Statistics divides Australia into five remoteness areas on the basis of road distances to urban centres and services (Australian Bureau of Statistics, 2018). These areas include major cities, inner regional areas, outer regional areas, remote areas and very remote areas. In Victoria, where this research was conducted, areas categorised as major cities includes both metropolitan Melbourne and metropolitan Geelong. There are no areas in Victoria that are categorised as very remote areas. The term non-metropolitan is used in this study to refer to all Victorian locations categorised as inner regional, outer regional and remote areas. Such a broad label was used because the de-identified data provided by DET did not allow a more refined categorisation of location. The term rural is used to refer to a subset of the non-metropolitan category, and includes locations that may be categorised as inner regional, outer regional and remote areas, but are not in a regional city.
1.9 Thesis structure

This thesis follows a relatively traditional thesis structure of literature review, conceptual framework, methodology, results, discussion and conclusion. Somewhat less conventional, is that parts of this thesis incorporate excerpts from papers and chapters that I authored or lead authored as part of this study, and that have already been published in peer reviewed journals and books. These excerpts and their source are clearly identified where they appear. In referring to this research I use phrases such as “my research…” for additional transparency. The use of pronouns such as “I” or “my” is not uncommon in research literature (Hyland, 2003).

Chapter 2 reviews the international literature about contributors to effective STEM education, both those with an evidence base, and those promoted by Australian STEM education strategies. It also reviews the literature about impediments to implementing effective STEM education. Following this is an exploration of the current state of STEM education in rural schools, and an overview of the limited research into rural school STEM education. Finally, the nature of researching STEM success in Australia is considered, including the challenges associated with measuring whole school STEM success.

The conceptual framework guiding this thesis is explained in Chapter 3. This framework draws upon Appreciative Inquiry as a strengths-based approach to researching whole school STEM success, and the theory of Practice Architectures, as a lens for examining the practices, and factors enabling these practices, that may have contributed to this school STEM success. Combined they provide the theoretical justification guiding this study’s approach which focuses on practices that contribute to school success and privileges the views of those who contributed to and/or experienced these practices.

Chapter 4 presents an overview of the study’s methodology before detailing the methods employed in both Phase One and Phase Two. Phase One repurposed quantitative data routinely collected by the Victorian DET about senior student enrolment and achievement in STEM subjects in order to identify relatively high STEM performing rural schools. It proposes the “School STEM Success Criteria”, drawing upon the literature in Chapter 2 to establish the content validity of the criteria, before describing how data analysis will both establish the content validity of the criteria, and be used to identify high STEM performing schools. The selection of four rural schools identified as high STEM performing for case study in Phase Two is described, before detailing the overall case study design, data
collection and analysis, including measures to contribute to the validity and reliability of findings. The chapter ends by outlining the measures used to ensure the ethical collection and management of the study’s data.

The findings from Phase One are presented in Chapter 5, first establishing the construct validity of the School STEM Success Criteria, and then demonstrating that 25 non-metropolitan schools can be considered as relatively high STEM performing using these criteria. Phase Two’s findings are detailed in Chapter 6, which presents the case studies of four high STEM performing rural schools selected from those identified in Phase One. The case studies of each individual school present a school profile, before exploring the practices contributing to the school’s STEM success, and the practice architectures enabling those practices. Chapter 6 concludes with a multi-case synthesis that compares and contrasts the practice and practice architecture themes across the four sites.

Chapter 7 discusses the findings of this project in light of both the international STEM education research literature, and Australian STEM education policy. It provides an analysis of the practices contributing to the STEM success of the rural schools in Phase Two relative to the elements promoted in the literature as contributing to school STEM success. This analysis reveals that these of these elements were present at the schools to varying degrees, as well as identifying other practices believed to contribute to the STEM success of the case study schools that are not well represented in the STEM education literature.

The thesis concludes with Chapter 8, offering an overview of the key findings of the project, along with a summary of the limitations, before highlighting the significance of the findings for STEM education researchers, policy makers, and rural schools.

1.10 Summary

This introductory chapter provides background information about the importance of STEM education, and the lack of a common understanding of what effective STEM education is, highlighting the need for further research into STEM education. It then explores the relatively poor performance of Australian students in terms of participation, engagement and achievement in STEM education, performance that is generally even poorer for students attending rural schools. The chapter presents the argument that there is a lack of research into STEM education in rural contexts, establishing the need for the research documented in this thesis.

The chapter presents the three research questions guiding this project:
1. Which rural Victorian government schools performing better than expected in STEM education?
2. What practices are believed to have contributed to the success of these high STEM performing rural schools?
3. To what extent do the practices of high STEM performing rural schools reflect factors proposed in the literature as contributing to school STEM success?

A brief overview of the design of the two phases that address these questions is offered. Finally, there is a brief overview of the structure of this thesis.
Chapter 2: Literature Review

This chapter includes a number of excerpts from my published work. Specifically, excerpts have been taken from:

**Murphy, S., MacDonald, A., & Danaia, L. (2020).** Sustaining STEM: A framework for effective STEM education across the learning continuum. In A. MacDonald, L. Danaia, & S. Murphy (Eds.), *STEM education across the learning continuum: Early childhood to senior secondary* (pp. 9-28). Springer. (See Appendix A).

https://doi.org/10.1177/1478210318774190 (See Appendix B).

These publications are part of my PhD work. The first publication describes a framework of effective STEM education that my colleagues and I developed and supported through extensive use of international research into STEM education, its component disciplines, and associated pedagogies. The second publication presents a critique of Australian STEM education strategies in the light of themes my colleagues and I identified in the extant international STEM education literature. Each excerpt is clearly identified with a brief introduction, a reduced font size, and narrowed margins.

### 2.1 Preamble

This chapter explores what is known about effective STEM education, and the research into school-based impediments to its implementation. It then considers Australian policy directions in STEM education and how they compare to the international STEM education evidence base. A key equity issue for Australia is the relatively poor performance of rural schools in STEM education. The chapter explores the STEM education performance of rural schools, alongside factors impacting on rural school performance in general. It considers research into rural school success, highlighting the paucity of research into rural school success in STEM. Expanding the evidence base for effective STEM education in Australian contexts has been identified nationally as a key action for improving school STEM education (Education Council, 2015). This chapter explores the dominant modes of research activity into STEM success in Australia, before advocating for an approach all but absent from
Australian STEM research, that of investigating practices leading to whole school STEM success as measured by school STEM performance. Finally, approaches to measuring school STEM performance are explored, building an argument for the content validity of the measures of STEM success used to identify schools for case study in this project.

2.2 What is effective STEM education?

STEM education is a relatively young field with limited, though developing, theoretical underpinnings. This section presents excerpts from a book chapter that I lead authored that drew on the international literature associated with STEM education, as well as research in its component disciplines and associated pedagogies, to describe the components of effective STEM education (Murphy, et al., 2020, see Appendix A). This chapter presented effective STEM education as comprised of three interacting components: STEM knowledge; STEM skills; and STEM engagement. It further described effective STEM education as attending to the development of these capabilities throughout a student’s learning journey from early childhood, through to the conclusion of secondary schooling and beyond, and effective STEM education does so for all learners of all genders and cultural backgrounds. The chapter went on to outline the implications of this view for STEM educators, the selection of appropriate STEM education pedagogies, and the STEM learning environment. Excerpts from this chapter are presented here to describe what the existing research literature suggests about effective STEM education. The following excerpt describes what it means for an individual to become “STEM capable”, in terms of their STEM knowledge, their STEM skills, and their STEM engagement:

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

In developing this stance, we draw on broad understandings of STEM from differing perspectives. [We draw] together research literature from STEM education - literature pertaining to STEM in an integrated manner as well as drawing on literature related to the individual disciplines. [We also] draw together perspectives across the trajectory of STEM education from early childhood through to senior secondary and beyond. Further, [we consider] research into
STEM education for females, students of different cultures and racial backgrounds, students from rural and remote areas, and students from different socio-economic backgrounds.

**STEM Knowledge**

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

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

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

**STEM Skills**

STEM capable individuals have the skills to pose, ponder, and solve STEM-related problems that are real and authentic to their personal worlds. Industry and governments call for STEM education to equip students with “STEM skills” with little guidance as to what these skills may be (Australian Industry Group [AIG], 2015; CEDEFOP, 2014; Morgan & Kirby, 2016). Some authors have used employer surveys to identify extensive lists of STEM skills required by STEM industries (Jang, 2016; Prinsley & Baranyai, 2015). Others have aimed for a more manageable set of STEM skills by drawing the 21st-Century skills (Bybee, 2013). Many
researchers focus on the skills associated with complex problem solving and the STEM processes implemented to innovate and solve problems (for example, Asun, 2014; English et al., 2017).

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

**STEM Engagement**

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

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

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

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

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

(Murphy et al., 2020, p. 10-13, see Appendix A)

The chapter goes on to argue that STEM knowledge, STEM skills, and STEM engagement need to be developed throughout the learning journey, beginning in early childhood and continuing through to senior secondary school and into further education. The following excerpt described this view of STEM education across the learning journey:

**STEM across the Learning Journey**

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

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

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

(Murphy et al., 2020, p. 13, see Appendix A)

The chapter highlighted equity as a prominent theme in the literature, arguing that effective STEM education must cater for the needs of all learners. The following excerpt describes this aspect:

**STEM for All Learners**

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

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

(Murphy et al., 2020, pp. 13-14, see Appendix A)

Following this overview of the demands on STEM education to develop the knowledge, skills and engagement of all learners throughout their learning journey, our chapter considers the literature available internationally about the educational practices considered best able to meet these demands. The following excerpt considers pedagogies commonly associated in the literature with effective STEM education:

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

**STEM Educational Practices**

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

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

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

(Murphy et al., 2020, pp. 14-15, see Appendix A)
Finally, the chapter draws together literature about the role educators, educations leaders and learning environments must play in delivering effective STEM education. The following excerpt describes this aspect:

**STEM Educators**

Educators themselves need to be STEM capable, as well as possess additional characteristics that allow them to foster STEM knowledge, skills and engagement in their students through appropriate educational practices. Educators draw on a range of learning theories to inform their practice (Starkey, 2012). The STEM capable educator draws primarily on three related learning theories: personal constructivism, social constructivism (Skamp & Preston, 2018) and connectivism (Starkey, 2012). Personal constructivism sees individuals building understanding through interaction with the material environment. (Skamp & Preston, 2018). Social constructivism sees learning driven by communication with others and interaction with the social environment. Connectivism sees technology extending interactions beyond the immediate physical environment, and knowledge creation involving making connections between people and information sources (Starkey, 2012). Connectivism views knowledge as unstable, with new understandings evolving and others being superseded or becoming redundant. Between them, these learning theories underpin [effective STEM education], positioning knowledge as uncertain and socially constructed, STEM skills as developed through interaction with the real world, and engagement fostered through authentic learning activities and social relationships.

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

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

**STEM Learning Environments**

The learning environment is the physical, social, and cultural context of learning (De Nobile et al., 2017). Drawing from this definition, the STEM learning environment refers to the surroundings, resources, relationships, expectations and norms where STEM learning takes place. The following excerpt discusses the literature about learning environments that support effective STEM education:

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

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

**STEM Leaders**

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

(Murphy et al., 2020, pp. 15-17, see Appendix A)

2.3 School-based impediments to effective STEM education

The previous section draws together the key elements that research suggests contribute to effective STEM education. However, research also has much to say about challenges to implementing effective STEM education. Some of these, schools control have little control over, such as student socioeconomic backgrounds, family support, gender, and culture (Frenzel et al., 2010; Holmes et al., 2018; Jeffries et al., 2019), while others are well within the remit of schools and educators to influence. Barriers to effective STEM education that are within educators’ and schools’ power to overcome are profiled in this section.

2.3.1 Resistance from the disciplines

There is some resistance to integration of STEM from advocates of the individual STEM disciplines who hold concerns for the integrity of their particular subject. There are concerns that mathematics benefits the least from integration, with STEM integration commonly focusing upon science outcomes and only incidentally exploring mathematics concepts (English, 2016). Questions have arisen around how compatible STEM integration is with students building a full and assessable understanding of scientific and mathematical concepts (Coad, 2016; Moore, 2014). Proponents of the technology and engineering disciplines, while celebrating school STEM as an opportunity to increase the profile of their fields (Bybee, 2010), are concerned their relatively young disciplines will not be well served in a merger with the established disciplines of Science and Mathematics (Kelley, 2010, 2012). They worry that school STEM presses technology and engineering into servitude, resulting in the exclusion of aspects of these disciplines that do not align with, or serve to improve the learning of, science and mathematics (Williams, 2011).
2.3.2 A lack of consensus about the forms of STEM integration and inquiry.

Pushing beyond these concerns of disciplinary integrity, there is also disagreement around the desired degree and form of integration. Kelley (2010) explores the potential for STEM teaching to be multidisciplinary (the distinct disciplines addressing different aspects of the one task) or interdisciplinary (disparate knowledge drawn together from multiple fields to produce new ways of thinking). Moore (2014) sees STEM integration as either context integration or content integration. Context integration uses a problem or real-life situation to organise the teaching of content from the separate disciplines. Content integration identifies synergies between the different STEM fields to design learning tasks that address learning objectives from multiple areas. Sanders (2009) advocates ‘Integrative STEM education’, a catch-all for inquiry programs drawing on two or more of the STEM fields, or even one STEM subject and other school subjects. Bybee (2010) suggests a pragmatic model where the individual STEM subjects are maintained and supplemented by shorter instructional units with the STEM disciplines integrated around a personal, social, or global context. Williams (2011) takes a step further back calling for interaction of the separate disciplines initiated by teachers working collaboratively at the school level where it will enhance student learning, rather than programmed integration.

Similarly there is a lack of consensus about what inquiry-based instruction is (Marshall et al., 2017). In Australia, there is no generally endorsed model of inquiry, despite inquiry-based approaches being included in the Australian Curriculum (Fitzgerald et al., 2016). The inquiry label is applied to a spectrum of activity, from confirmatory inquiry, where students follow a set procedure to produce a known answer to a provided question, through to open inquiry, where students generate their own questions, carry out their own investigations, and communicate their results (Fitzgerald et al., 2019). Inquiry-based learning approaches have been criticised as ineffective, however these criticisms are often associated with their implementation without appropriate scaffolding and structure (Barron & Darling-Hammond, 2010; Fitzgerald et al., 2016). Concerns about the effectiveness of inquiry-based learning has led to some educators favouring more transmissive modes of teaching (Fitzgerald et al., 2019).

2.3.3 Impediments due to curriculum design and assessment.

There are arguments that the curriculum design and assessment practices further impede effective STEM education (Timms et al., 2018). The Australian Curriculum describes the
STEM disciplines separately and was designed with the intention that most time would be allocated to teaching Mathematics, followed by Science, and least time allocated to Technologies (ACARA, 2012). In fact, the Technologies curriculum was designed to be optional for students in Years 9 and 10, (ACARA, 2012). The separation of the STEM disciplines is exacerbated by available assessments usually being discipline specific (Honey et al., 2014). Further, in Australia, the National Assessment Program Literacy and Numeracy (NAPLAN) test, is seen as emphasising the importance of mathematics at the expense of the other subjects (Klenowski & Wyatt-Smith, 2011; Timms et al., 2018). All these factors work against the implementation of STEM as an integrated study. Similarly, curriculum and assessment can impede the implementation of inquiry-based learning. There are arguments that the current Australian Curriculum is too broad to allow room for the deep content exploration that inquiry-based learning demands (Fitzgerald et al., 2019). Inquiry-based learning requires higher order thinking, however available assessments, including high-stakes assessments such as NAPLAN, emphasise lower order thinking, driving more teacher directed forms of instruction (Marshall et al., 2017).

2.3.4 Technical barriers

Finally, the conventional forms of school organisation act as impediments to effective STEM education. The integrated, inquiry approaches associated with STEM education requires flexible and generous learning time allocation to allow students to engage deeply in real-world inquiry, yet secondary school learning is generally organised around a rigid timetable (Barron & Darling-Hammond, 2010; Rennie et al., 2012). Rennie et al. (2012), after many years of research in Australian schools as well as international contexts, suggest that a small and stable team of teachers sharing planning, curriculum materials, assessment, and, sometimes, instruction, is required to effectively deliver programs that integrate disciplines. They suggest that this teaching team should have significant planning time and responsibility for a relatively small group of students. However, in secondary schools around Australia, STEM is still largely delivered as the distinct subjects of Science, Mathematics, and Technology (Marginson et al., 2013), and teachers cite large class sizes, limited resources, and limited time due to administration demands as impediments to inquiry learning (Fitzgerald et al., 2019).
2.3.5 STEM educator capacities

Effective STEM education demands highly skilled STEM teachers. Unfortunately, Australian schools are struggling to staff Science and Mathematics classes with qualified teachers, with large proportions of these classes taught by teachers without teaching qualifications in these disciplines (Marginson et al., 2013). The inclusion of Engineering further complicates the demands of teaching STEM, as it is not a distinct part of traditional school structures (Bartholomew, 2015), nor pre-service teacher education. Secondary school teachers are prepared to teach one or two discrete specialist disciplines – so are ill prepared to deliver a merger of the four fields. It is arguable that primary school teachers might be better placed to implement STEM education, accustomed as they are to integrating content from across disciplines. However, there is a shortage of primary school teachers confident and expert in teaching science and mathematics (Marginson et al., 2013). The inquiry-based nature of STEM poses further challenges to teachers. Teachers often do not have the confidence, the time, or the pedagogical knowledge to effectively implement inquiry-based learning (Fitzgerald et al., 2019; Makar & Fielding-Wells, 2018; Marshall et al., 2017; van Uum, Verhoeff, & Peeters, 2016). This lack of self-efficacy and competence frequently leads to teachers relying upon teacher directed instruction (Barron & Darling-Hammond, 2010; van Uum et al., 2016).

2.4 How is Australia hoping to implement effective STEM education?

In response to the economic and social imperatives outlined in Chapter 1 of this thesis, the push to improve school STEM education in Australia has taken on a real urgency (Gough, 2015). In December of 2015 the Australian Education Ministers endorsed the National STEM School Education Strategy (Education Council, 2015). Since then, most individual State Education Departments have released STEM policies that echo many of the national strategy’s goals and aims, though each with their own jurisdictional character (New South Wales Department of Education, 2017; Queensland Department of Education and Training, 2016; South Australia Department of Education and Childhood Development, 2016; Tasmanian Department of Education, 2017; Department of Education and Training Victoria [DET Victoria], 2016a; Western Australia Department of Education, 2016).

As part of this study, I led the development of a paper that analysed the various Australian STEM education strategies, exploring how the policies conceptualise STEM education, the rationale they present for planning to improve STEM education, and the actions they recommend or intend to take to achieve this improvement (Murphy, MacDonald,
At the time of writing that paper, the Australian Capital Territory (ACT) indicated it had adopted the national strategy, and the Northern Territory reported that its STEM strategy was still under development, so these jurisdictions were not discussed in the paper. Excerpts from the paper are included in this section to provide an analysis of how Australia hopes to implement effective STEM education relative to the key themes in the international STEM education literature discussed previously in Section 2.2.2. Throughout the paper various jurisdictional strategies are referred to using abbreviations for each state. These abbreviations are explained in Table 1.

Table 1
Australian jurisdictions with a STEM education strategy

<table>
<thead>
<tr>
<th>Jurisdiction*</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>National</td>
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<tr>
<td>New South Wales</td>
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<td>Queensland</td>
<td>QLD</td>
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<td>South Australia</td>
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<td>Tasmania</td>
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<td>Victoria</td>
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<td>Western Australia</td>
<td>WA</td>
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*The Australian Capital Territory has adopted the national strategy, and, at the time of writing, the Northern Territory reported that their STEM strategy was under development.

2.4.1 Australia’s approach to developing STEM knowledge and skills

In the analysis I lead of Australian STEM education strategies, the term ‘capabilities’ was used to refer to the knowledge and skills to be developed through STEM education:

“[S]tudent STEM capabilities is a key element of the way each of the Australian strategies conceive of STEM education. Understandably, STEM discipline knowledge and skills are prioritised among the strategies. However, the interdisciplinary capabilities of problem solving, critical analysis, and creative thinking are even more prominent. Capabilities associated with collaboration and digital technologies are also evident, though with less consistency across the strategies. Furthermore, individually the strategies present a range of other capabilities which are important for STEM, such as communication, interdisciplinary thinking, independent thinking, and inquiry skills.

The need to improve the STEM capabilities of Australians was a strong theme in the rationales of all the strategies. In all but the Tasmanian rationale, the emphasis on STEM capabilities is associated with the need to prepare STEM skilled workers to take up positions in the growing STEM sector, and to ensure a globally competitive economy. Some rationales also
speak more generally of the need for improved STEM capabilities in response to a rapidly changing world (QLD, VIC). Less frequently mentioned is the role STEM capabilities play in ensuring individuals lead fulfilling lives as positive community members (TAS, WA). Several strategies cite Australian students’ slide in STEM enrolments and international testing of STEM skills and knowledge as a reason to address STEM education in Australia (National, SA, QLD, VIC).

The strategies adopt a range of actions to improve student STEM capabilities. Three strategies include actions to improve the tools to describe and track the development of STEM capabilities (National, TAS, WA). Despite creativity, critical thinking and problem solving being integral to each strategy’s description of STEM education few had explicit actions aimed at building these capabilities. Three strategies had actions for problem solving (National, QLD, VIC), three for creativity (National, QLD, WA), and three for critical thinking (QLD, VIC, WA). Similarly, though digital literacy was a common feature of the way strategies conceived of STEM education only three of the strategies have a strong emphasis on building student digital literacy, supported through resourcing and enrichment opportunities (National, QLD, VIC).

However, across the strategies, the desired STEM capabilities were not clearly articulated. In some cases, aspects of the Australian Curriculum’s “general capabilities” (ACARA, 2017b) are referenced (e.g., National, VIC), offering some guidance; however, the way these skills manifest in STEM education is not described. This lack of clarity reflects the STEM education literature, where there is still a need to clearly articulate for educators how these capabilities are to be exercised in STEM learning environments.

(Murphy, MacDonald, Danaia, & Wang, 2019, pp. 128-132, see Appendix B)

2.4.2 Australia’s approach to developing STEM engagement

The analysis considered how the Australian strategies viewed engagement in STEM education:

Each of the strategies acknowledge the role of affect in effective STEM education in their conceptualization and/or rationale, though generally this element has only minor emphasis. Strategies tend to express their intent with vague phrases like ‘lift student engagement’ (National, p. 3) or ‘encourage greater interest…in STEM’ (WA, p. 2). While it is encouraging that dispositions such as interest, curiosity, aspiration, and confidence are cited within the strategies as being important for initiating and sustaining students’ motivation to pursue STEM learning and career paths, there is little attempt to operationalise these terms. Only the Tasmanian strategy flagged motivational constructs such as student self-direction and growth mindset that have been found to improve learner engagement in STEM.

Further, only three of the strategies include actions explicitly aiming to impact on student disposition (National, VIC, WA). These actions focus on building aspirations, curiosity and confidence. The actions explicitly identified are limited to building industry partnerships, a
mathematics challenge, a research-based Early Childhood numeracy program, and delivering STEM education professional learning. Given the strong evidence showing the role of affect on student success in STEM and engagement in STEM pathways, the limited consideration of ways to enhance STEM dispositions is a significant shortcoming across the Australian STEM strategies. (Murphy, MacDonald, Danaia, & Wang, 2019, p. 132, see Appendix B)

2.4.3 Australia’s approach to improving STEM education across the learning journey

The paper discussed STEM across the learning continuum in terms of a student’s STEM education trajectory, which “is taken to include their STEM learning journey from early childhood through to senior secondary school and beyond” (p. 126). In considering the treatment of STEM education trajectories by the Australian STEM education strategies, the paper said:

There is some acknowledgement of STEM education trajectories in the way STEM is conceived by each of the strategies, though Tasmania and Queensland limit this to facilitating career pathways. Similarly, all rationales, implicitly or explicitly, give some consideration to STEM education trajectories. Universally, the rationales consider the role of STEM education in preparing students for future careers. Three of the rationales argue for the importance of STEM education to ensure senior secondary students continue on STEM learning pathways (National, QLD, VIC). Two of the rationales also acknowledge that STEM education begins in early childhood (National, VIC). Only the Victorian rationale makes explicit reference to stages of learning between early childhood and senior secondary, with a discussion of disengagement in STEM between Year 6 and Year 9.

Encouragingly, all strategies have actions focused on trajectories, with actions aiming at STEM education at the beginning and end of the formal learning journey. Aspiration building measures dominate, with all strategies including actions focused upon enhancing awareness of, and access to, career pathways and post-secondary opportunities throughout the schooling years. The literature argues that STEM education should begin well before children commence school, however, only three strategies have actions explicitly directed at STEM education in the early childhood years (National, SA, VIC). The research literature also makes it clear that each step of the learning journey is key to the development of a student’s STEM capabilities and dispositions. However, only Victoria and South Australia have explicit actions addressing STEM education for other stages of learning, and both only focus on Years 7 and 8. (Murphy, MacDonald, Danaia, & Wang, 2019, p. 133-134, see Appendix B)
2.4.4 Australia’s approach for providing STEM education for all learners

The paper also considered how the various Australian jurisdictions viewed the equity issues that STEM education should address:

… the extant research identifies equity issues for key groups in STEM education in Australia…

Five strategies (NSW, SA, TAS, QLD, WA) address equity in their conceptualisation of STEM education. Of these, all except Queensland used sweeping statements such as “STEM education is for all students”, merely implying the inclusion of groups that are known to be marginalised. Only Queensland explicitly identified girls and Indigenous students as groups requiring particular support, consistent with the research literature.

Three of the STEM strategies (National, VIC, SA) made explicit reference to equity issues in their rationales. The National strategy nominated girls, Indigenous students, students from low socio-economic backgrounds, and students from non-metropolitan areas, as groups that need to be considered. The South Australian rationale explicitly discussed the under-representations of women and Indigenous people in STEM, and the Victorian rationale had a strong focus on girls in STEM education, with some mention of the impact of student socio-economic background. Four strategies (QLD, SA, VIC, WA) included actions explicitly aiming to impact on equity in STEM education, and these were limited. However, the few actions articulated relied heavily on having impact through short term interventions such as camps for girls, mentoring programs for Indigenous children, and online STEM enrichment programs for non-metropolitan and disadvantaged communities.

(Murphy, MacDonald, Danaia, & Wang, 2019, p. 133, see Appendix B)

2.4.5 STEM educational practices being promoted in Australian schools

The analysis revealed no common stance on the place of integration in STEM education, though more agreement around other STEM education practices:

All but the Victorian strategy include STEM educational practices in the conceptualization of STEM education. The practices identified have a strong real-world and inquiry orientation, however there is no consensus among the strategies as to whether STEM education should be delivered through the discrete disciplines, or as a learning experience where the disciplines are integrated, with the strategies variously describing “STEM” as being four individual disciplines, cross-disciplinary, and/or inter-disciplinary.

To support building these STEM capabilities and dispositions, the strategies outline actions to transform educational practices. Encouragingly, given the evidence supporting inquiry learning in STEM education, the majority of strategies (National, NSW, SA, TAS, WA), have actions targeted at encouraging the adoption of inquiry or PBL pedagogies. Three strategies include actions aimed at ensuring STEM education is presented in an integrated way (NSW, TAS,
It is clear in the literature that the impact of both integrated curriculum and inquiry learning varies according to approach, context, and cohort; however, the strategies provide minimal description of how they conceived of these practices. All the strategies advocate building partnerships with industry, other educational institutions and the wider community, to improve the quality of STEM education (e.g., National, WA). While this has intuitive appeal, there is not yet conclusive evidence to support such actions (Gamse, Martinez, & Bozzi, 2017).

Three of the strategies (National, QLD, VIC) also place significant emphasis on digital learning practices. Each of these strategies establish a baseline action of implementing the set digital literacy curriculum. Victoria and Queensland have actions are focused on extra-curricular measures such as competitions. The remaining actions included the provision of software for secondary schools and the support of digital learning experiences for early childhood. These actions do not appear to be a strong match to those described in the literature expanding access to learning environments, or improving problem solving and motivation for all students.

(Murphy, MacDonald, Danaia, & Wang, 2019, pp. 132-133, see Appendix B)

2.4.6 Australia’s approach to developing its STEM educators

There was strong agreement across the strategies on the importance of teacher capacity for effective STEM education:

The research literature identifies a need for educators with sound STEM content knowledge, confidence to deliver STEM education programs, and engaging STEM pedagogical approaches. Only one jurisdiction (QLD) explicitly describes the role of educators in their conceptualisation of STEM education; however, five of the rationales (National, NSW, QLD, SA, VIC) describe the importance of educator capacity for improving STEM education. These rationales highlight the importance of building teacher confidence and competence, both in terms of STEM expertise and engaging STEM pedagogy.

All jurisdiction strategies, bar the Tasmanian, direct actions at raising the skills of educators. Each of these adopt actions to identifying and/or training of excellent STEM practitioners, and schools, to act as support and role models to others. There are several actions to improve the capacity and confidence of early childhood and primary teachers (National, SA, VIC), and other actions to provide mentoring to inspire secondary school STEM teachers (SA, VIC). Only two of the strategies (SA, WA) have actions directed at improving school leaders’ capacity to drive the implementation of STEM education.

(Murphy, MacDonald, Danaia, & Wang, 2019, p. 134, see Appendix B)
2.4.7 To what degree do the Australian STEM education strategies align with the STEM education literature?

The analysis reveals that while there is some alignment of aspects of the Australian STEM education strategies to the STEM education literature, there were key themes from the literature that the strategies largely overlooked:

As a group, Australia’s STEM education strategies align to the STEM education literature to some degree, however no single strategy can be said to comprehensively address all the important themes arising in the STEM education literature. Several of the themes are addressed by the majority of the strategies. There is an emphasis in the strategies on developing STEM capabilities in students, and achieving this through research-supported educational practices such as inquiry and problem based learning. Building educator capacity is seen as a key action for improving STEM education. The strategies strongly favour actions aimed at improving educator knowledge and confidence, and supporting the adoption of STEM education practices.

Other themes from the literature are less well addressed. While collectively the strategies acknowledge STEM education as a key part of a child’s entire learning journey, the strongest emphasis is on facilitating career pathways when exiting school. Less than half the strategies explicitly focus on STEM education in early childhood and even fewer consider maintaining student learning trajectories in between. Though most strategies allude to the importance of STEM dispositions and acknowledge various equity issues, these matters receive less explicit treatment in the articulated actions.

The recently released Australian STEM education strategies are designed to guide the actions of educational leaders and practitioners for up to a decade. While it is encouraging to see some of the themes from the literature into effective STEM education reflected in the strategies, it is concerning that issues regarding STEM dispositions, equity, and transitions within and between educational sectors, are not given significant attention. The implication of these deficits is that educators and leaders responding to the various strategies may [be] miss addressing aspects crucial for improving STEM education for all children at all stages of learning.

(Murphy, MacDonald, Danaia, & Wang, 2019, p. 134, see Appendix B)

This analysis demonstrates that as a set the Australian STEM strategies reflect some of the elements known to contribute to effective STEM education, though none comprehensively address all the prominent themes in the research literature (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). Further, the strategies collectively advocate for practices that are yet to establish a strong research base in the STEM education literature, such as schools building partnerships with industry, tertiary institutions, or community groups, and extra-curricular digital learning interventions. The more speculative
measures included in the strategies, alongside practices with a stronger foundation in research, are considered in Chapter 7 of this thesis when addressing the research question, “To what extent do the practices of high STEM performing rural schools reflect factors proposed in the literature as contributing to school STEM success?”

2.5 STEM education in rural Australia
The relative underperformance of students attending school in non-metropolitan areas is one of the equity issues in STEM engagement and achievement that collectively the Australian jurisdictions STEM strategies call to be addressed (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). The Victorian STEM strategy supports some, though limited, interventions targeting rural and regional schools including training primary school teachers as mathematics and science specialists, and providing free access to programs delivered by Science and Mathematics Specialist Centres (none of which are located in rural areas) (DET Victoria, 2016a). This section of the literature review explores STEM education in rural Australian schools. It first considers the current performance of rural students and schools in STEM education. It then explores a range of factors believed to impact on rural student engagement and achievement in STEM education. Finally, it reviews the scant literature about STEM education success in rural Australian schools.

2.5.1 STEM performance in rural schools
International, national, and jurisdictional assessments suggest that rural Australian students are outperformed by their urban counterparts in STEM. The Programme of International Student Assessment (PISA) testing suggests the average gap between metropolitan and rural 15 year olds is the equivalent of a year or more of learning in both science and mathematics, and that metropolitan schools have a far larger proportion of high performing students compared to rural schools, and significantly fewer low performing students (Thomson, De Bortoli, & Underwood, 2017). Trends in International Mathematics and Science Study (TIMSS) testing suggests a similar disparity in achievement in mathematics and science for students in Year 4 and Year 8 (Thomson, Wernert, et al., 2017). The 2016 National Assessment Program – Literacy and Numeracy (NAPLAN), which aims to test all Australian children, showed that average Year 3, Year 5, Year 7 and Year 9 numeracy results deteriorated the further you lived from major cities, while the proportion of students just at or below national minimum benchmarks increased dramatically (ACARA, 2016a). Trend data from the National Assessment Program (NAP) Science Literacy testing, which tests a sample
of year 6 students from across Australia, shows a significant and widening gap between the performance of metropolitan and rural students in Science (Connolly, 2017). Rural students are also behind in Information and Communication Technology (ICT) Literacy as measured by the NAP ICT Literacy tests sampling Year 6 and 10 students from across Australia (ACARA, 2018). Finally, my research has found that on average, metropolitan students earned higher results in every Year 12 science, mathematics and technology subject offered in Victoria from 2014 to 2016, apart from Agricultural and Horticultural Studies, and one of the three digital technology subjects (Murphy, 2018a, 2019a, 2019b).

While the link between location and STEM achievement is clear, the evidence about the impact of school location on STEM engagement is limited and occasionally contradictory. The 2015 PISA survey of Australian students’ motivations and beliefs in science revealed that metropolitan students were more likely to view science as contributing to their career pathway and job prospects. Furthermore, metropolitan students were more likely to report an interest in science and enjoyment in learning science (Thomson, De Bortoli, & Underwood, 2017). Similarly, Lyons and Quinn (2010) found that students attending small rural or remote schools were less likely to enjoy science subjects or to prefer science subjects to other subjects. However, my research comparing Victorian students’ participation in Year 12 science found little difference in the participation rates in any of the science subjects by location, where those particular science subjects were available at their school (Murphy, 2018a). In mathematics, PISA surveying revealed apparently conflicting responses, with students from rural schools having the highest motivation to learn mathematics, however the lowest self-efficacy, and perceived control in mathematics (Thomson et al., 2013). My research found that in Year 12, nonmetropolitan students are more likely to enrol in entry level mathematics, and where available, less likely to take advanced mathematics, than metropolitan students (Murphy, 2019b). The impact of location on student engagement with technologies studies is relatively unexplored. My research found that nonmetropolitan schools had much larger enrolment proportions in VCE design technology and engineering subjects than metropolitan schools, and only slightly lower enrolment proportions in digital technology subjects (Murphy, 2019a).

While cumulatively this research presents a deficit view of rural school STEM performance, it is worth noting that much of it is based on data aggregated at a national level. This form of aggregation tends to hide any highs and lows in the data sets (Halsey, 2017). This is certainly true for this author’s research, where though aggregate data demonstrated lower achievement and participation in senior science, technology and mathematics subjects
in rural schools, there were rural schools that performed very strongly in these STEM subjects, despite their location or socioeconomic status (Murphy, 2018a, 2019a, 2019b). These exceptions to the general trend in rural STEM education are important as “it is the highs that have the potential to provide innovative and fresh ways to improve education achievements for regional, rural and remote students.” (Halsey, 2017, p.11). It is the identification and study of these “highs” in rural STEM education that are the focus of the research described in this thesis.

### 2.5.2 Factors impacting rural school STEM performance

There are a range of factors believed to contribute to the underperformance of Australian rural schools in general, including the socio-economic status of rural communities, smaller school size, higher proportion of Aboriginal students, high teacher turnover, school isolation, and lower educational expectations (Centre for Education Statistics and Evaluation [CESE], 2013). These factors interrelate and interact, impacting the learning and opportunities of rural students (Halsey, 2018). It is reasonable to assume that these factors also impact rural school STEM performance. The literature points to various interrelated factors particularly impacting STEM education in rural schools, including access to STEM subjects, STEM teacher capacity, demands on STEM teachers, mathematics education, resourcing, and learning expectations.

#### STEM subject access

My research found that rural schools are less likely to provide their students with access to many STEM subjects in Year 12, particularly advanced mathematics (Murphy, 2019b), physics, chemistry (Murphy, 2018a), and digital technology subjects (Murphy, 2019a). Where rural schools do provide particular STEM subjects, they are more likely than metropolitan schools to run these classes as composite classes where Year 11 and Year 12 students are taught in the same group (Lyons et al., 2006). Reviews of the international body of research literature about the impact of composite classes suggest that composite classes have a neutral to positive impact on student achievement and social development, however this research has largely been conducted in primary schools (Cornish, 2011; Cornish, 2014; Lloyd, 1999). Teachers, school leaders, and parents alike do not view composite classes in secondary schools as desirable (CESE, 2013). In particular, composite class arrangements in secondary schools are believed to deliver inadequate preparation and learning time, and poorer academic achievement. Rural secondary students view composite classes as a
deterrent to enrolling in advanced senior mathematics classes (McPhan et al., 2008). Distance education is also more likely to be employed in rural schools, and is also viewed unfavourably by students, as it is seen to require more self-discipline and effort (CESE, 2013; McPhan et al., 2008).

**STEM teacher capacity**

A partial explanation for poorer STEM subject access in rural schools, as well as rural school STEM performance in general, is the difficulty rural schools have in appropriately staffing these subjects (Lyons et al., 2006; Marginson et al., 2013; Weldon, 2016). Rural schools have difficulty recruiting qualified science and mathematics teachers (Handal et al., 2013). The further a school is from a metropolitan location, the more likely it will be running subjects taught by out-of-field teachers, particularly mathematics, science and digital technologies (Weldon, 2016). In fact, rural science, mathematics and ICT teachers report that they are two to three times as likely to be asked to teach subjects they are not qualified for, compared to teachers of these disciplines working in metropolitan schools (Lyons et al., 2006). Alongside the difficulties in recruiting qualified STEM teachers, the smaller size of rural schools may contribute to this phenomenon, as a relatively small staff is required to deliver a wide range of subjects (Weldon, 2016). Also concerning is that teachers working in rural schools, and those required to teach out-of-field, are often early career teachers with limited teaching experience (Handal et al., 2013; Weldon, 2016).

Rural schools also have difficulties building the STEM teaching capacity of the staff they have. Science and mathematics teachers in rural schools report they have limited opportunities for professional networking and poor access to professional learning opportunities (Handal et al., 2013; Pegg & Panizzon, 2011). They report that they lack adequate mentoring or oversight by those in school leadership (Goodpaster et al., 2012). In all, rural school science, mathematics and ICT teachers report higher levels of unmet professional development needs than teachers of these subjects in metropolitan schools (Lyons et al., 2006).

**Demands on STEM teachers**

Teaching out-of-field, teaching composite classes, and a lack of mentoring and networking opportunities all place an obvious additional load on rural school STEM teachers, however, there are other aspects of rural schools that place increased demands on STEM teachers. Smaller staff size in rural schools means that these schools do not have a large team of...
specialists, but instead require teachers to have broad expertise (CESE, 2013). Early career science and mathematics teachers in rural schools are often called upon to act as curricular experts and fulfil leadership roles within the school (Handal et al., 2013). These additional demands are perceived to contribute to the poor retention of STEM teachers by rural schools.

**Mathematics education**

Mathematics education is a particular concern with regard to the STEM performance of rural schools, given its status as a gate-keeper subject (Watson et al., 2016). Both mathematics achievement and engagement contributes to individuals succeeding in STEM education, and pursuing STEM occupations (Petersen & Hyde, 2017; Wang et al., 2015). Unfortunately, in addition to the discussed underperformance of rural students in mathematics testing, rural students report feeling less productive and competent in mathematics, and that their mathematics teachers are less supportive than teachers of applied subjects (Hardré, 2011). Rural students’ experience of mathematics education not only has implications for mathematics learning, but for student performance and aspiration in STEM more broadly. Student engagement and performance in mathematics learning should be a particular focus for rural schools (Watson et al., 2016).

**Resourcing**

Rural schools also confront resourcing issues in STEM education. Rural science, mathematics and ICT teachers reported greater unmet needs related to accessing educational sites to enrich student learning, compared to metropolitan teachers (Lyons et al., 2006). Similarly, these rural teachers felt that they did not have adequate resources and activities to support the learning needs of high performing students or students with additional learning needs. Finally, these rural teachers reported less access to ICT resources and the support required to effectively use these resources.

**Learning expectations**

Rural schools confront difficulties in maintaining high learning expectations, particularly in STEM education. Rural students, and their parents, tend to have lower expectations that they will progress to tertiary education (CESE, 2013). Rural mathematics teachers raise concerns about the challenge of holding high learning expectations where local employment opportunities do not require a strong academic achievement (Pegg & Panizzon, 2011). The smaller senior mathematics classes in rural schools posed difficulties for establishing
appropriately high benchmarks for student achievement (Pegg & Panizzon, 2011). Sustaining high expectations requires a broad range of curriculum offerings and opportunities for extension (CESE, 2013). As discussed, this is something rural schools struggle to offer, particularly in STEM. Rural students themselves nominate restricted senior school offerings and a lack of high performance expectations amongst peers, as factors contributing to lower career aspirations (CESE, 2013).

2.5.3 STEM education success in rural schools
Most research published about STEM education in rural schools adopts a deficit view, focusing on the problems experienced by rural schools, teachers and students, as is true of rural educational research in general (CESE, 2013). There is a dearth of published research into successful STEM education in rural Australian schools, or in similar contexts internationally. The little that is available can be categorised as examples of success achieved through either community relationships, place-based learning, STEM enrichment programs, or effective professional development.

*Place-based learning*

The most prominent theme is the scant literature about STEM education success in rural schools relates to the use of place-based learning. Place-based learning includes active learning opportunities located in the local community and environment (Alliance for Excellent Education, 2010). By shaping learning according to the characteristics of a particular place, place-based learning can mitigate against any disconnect between school and students’ lives (Smith, 2002). There are five common approaches to place-based learning focused upon cultural studies, nature studies, real-world problem solving, entrepreneurial opportunities, or inductions into community processes (Smith, 2002). Place-based learning arose to prominence in the 1970s and is now supported by a significant literature base. In the U.S., where schools are viewed as having traditionally delivered programs sited in the local area and drawing upon local resources, place-based learning gained significant interest from rural schools advocates and researchers in the early 2000s (Jennings et al., 2005). In Australia, place-based learning approaches are also promoted as an effective approach for rural schools (CESE, 2013; Halsey, 2018; Wildy & Clarke, 2010). However, there is very limited published research exploring the impact of place-based learning in Australian rural schools. One study offers evidence of the approach having positive impact, where a rural school embedded science learning in the local environment and collaborating with local
industry, community bodies, and government agencies (Aldous, 2008). The place-based learning approach was felt to help transition the school from a metro-centric view, where the school was seen as having a remote relationship with a distant city, to a “rural-cum-global” (Aldous, 2008, p. 47) orientation where students engage with issues of global significance in their immediate local context. There is somewhat more, though not extensive, evidence of the positive impact of place-based learning on STEM education in rural schools from the U.S. where local rural contexts and partnerships with local organisations are reported to enhance student learning in science and mathematics (Avery, 2013; Avery & Kassam, 2011; Clark et al., 2015; Hardré, 2011; Minner & Hiles, 2005; Peterson et al., 2015).

**Community relationships**

Strong community relationships can support STEM education in rural schools in ways other than facilitating place-based learning. Strong family-school connections and supportive relationships between rural schools and their communities can positively impact the educational outcomes of rural students (Barley & Beesley, 2007; Halsey, 2018; Hardré et al., 2009; Semke & Sheridan, 2012). Rural student relationships with their friends, and support from their teachers are strong predictors of aspirations (Watson et al., 2016). Rural schools can also extend parent aspirations for their children through career programs and counselling. There is also evidence that STEM teacher retention in rural areas is improved by teachers feeling they contribute to the local community, and by teachers gaining satisfaction from helping students see the connection between STEM and rural life (Goodpaster et al., 2012).

**Effective professional development**

The literature also suggests that STEM professional development for rural teachers should have particular characteristics. Effective professional development for rural mathematics teachers connects them to other teachers, and supports them to learn as part of active, collaborative teams (Goos et al., 2011; Pegg & Panizzon, 2011). Professional learning for rural mathematics and science teachers should be ongoing, and driven by local demands, such as student learning needs or other teacher-identified issues at their schools (Harmon et al., 2007; Jorgensen, 2016a; Pegg & Panizzon, 2011). This learning requires shared respect, trust and autonomy, and should be supported by experienced staff with high levels of content and pedagogical expertise (Harmon et al., 2007; Jorgensen, 2016a). Effective professional learning for rural mathematics teachers is supported by adequate time and space (Goos et al., 2011; Pegg & Panizzon, 2011). While none of these characteristics could be described as
particularly rural in nature, it does highlight that improved access to local, collaborative, school-based professional development could contribute to improving STEM education in rural schools.

**STEM careers and enrichment programs**

Finally, there is some evidence that STEM enrichment programs can improve rural students’ attitudes and aspirations in STEM. High achieving rural students reported benefits from participation in extracurricular STEM development programs delivered at their schools (Ihrig et al., 2018). Extended programs delivered offsite can also promote student attitudes towards engineering (Elam et al., 2012). These findings are supported by the general rural education literature that advocate for the use of explicit career education programs to raise rural students’ career awareness and aspirations (CESE, 2013).

### 2.6 Researching STEM success in Australia

Given STEM education is still relatively young as a distinct field, particularly in Australia (Blackley & Howell, 2015; Gough, 2015), its evidence base is limited but developing. Much of the evidence informing Australian STEM education policy relies heavily on international sources, for example Marginson’s (2013) international comparisons of STEM education is much cited. Australia’s policy response to issues in STEM education follow that of the US and UK (Blackley & Howell, 2015). However, even internationally, there is a call to improve the rigour of, and to fill gaps in, the school STEM research base, particularly regarding effective STEM classroom practice (Honey et al., 2014; House of Commons Science and Technology Committee, 2017). Australia’s National STEM School Education Strategy (Education Council, 2015) acknowledges the paucity of evidence around successful STEM and dedicates one of its five priorities for national action to “building a strong evidence base… [and]… impro[v]ing our understanding of what works in Australian contexts” (p. 10). Given the discussion in the previous section, it is important that rural schools be key contexts when building the Australian evidence base in STEM education.

Researchers investigating schools with successful STEM programs in Australia have tended to focus on researching practices prominent in the literature as contributing to effective STEM education. Schools selected for study are those implementing programs that align with practices the literature suggests contribute to STEM learning. Some schools are obvious STEM education research sites, such as schools established to specialise in STEM (e.g., Bissaker, 2014). Often the schools chosen are piloting new STEM programs (e.g.,
Albion & Spence, 2013; Hudson et al., 2012; Tomas et al., 2014). In many cases, these schools worked collaboratively with research institutions who were both the designers and the evaluators of these new programs (for example, ACARA, 2016b; Hudson et al., 2015). This approach to researching STEM education deepens our understanding of practices already represented in the literature about contributors to STEM learning, but it has some limitations. Researching programs selected on the basis that they are implementing practices already believed to improve STEM learning runs the risk of ignoring alternate practices successful in particular contexts. It also potentially encourages an opportunistic approach to selecting schools and STEM programs for study, where schools that are accessible to researchers, and/or schools able to access expert facilitated STEM initiatives are those that are most heavily researched. This risks the development of a largely metro-centric evidence base around effective school STEM practice, and potentially results in rural STEM education sites worthy of investigation going unrecognised.

Another dominant characteristic of STEM education research is a focus on the impact of relatively short term interventions or initiatives implemented at the classroom level (e.g., Bubnick et al., 2016; English et al., 2013; English et al., 2017; Llewellyn et al., 2016; McDonald & Howell, 2012; Tomas et al., 2014; Yanyan et al., 2016). Some research examines the impact of more extensive STEM education programs of a semester length or more (e.g., Ardito et al., 2014; Dixon & Brown, 2012; Molina et al., 2016; Nemiro et al., 2017; Redmond et al., 2011). This research gives significant insight into the short to medium term impacts of STEM education initiatives. However, given that school STEM success is impacted upon by factors from early childhood through to the end of secondary school, research that examines effective STEM education as a whole school endeavour is also desirable. Unfortunately, research into whole-school approaches to STEM education (for example, Hefty, 2015) is limited, with much of this research focused on specialist STEM schools (e.g., Bissaker, 2014; Lynch et al., 2017; Morrison et al., 2015; Subotnik et al., 2010) rather than STEM education in ‘regular’ schools.

This study addresses these gaps in the STEM education literature in three ways. First, it seeks out sites of high STEM education performance, rather than sites implementing programs believed to contribute to STEM success. This avoids pre-ordaining certain practices as components of all effective STEM education programs. Instead, it requires the identification of context specific practices contributing to effective STEM education at each particular site where there is high engagement and achievement in STEM. Second, this study focused explicitly on rural schools. Potential research sites were identified due to their STEM
education performance, not their accessibility to metropolitan centres. Finally, this study aimed to identify the array of practices that contributed to whole-school STEM success, and the conditions that enabled these practices. By investigating STEM successful schools, students’ entire STEM learning journey through the school was considered.

2.6.1 Measuring jurisdictional STEM success

In order to identify schools achieving STEM education success as potential research sites, a valid metric of STEM education success is needed. The various Australian STEM strategies tend to set goals and targets to be achieved through STEM education that can be used as a basis to measure jurisdictional performance in STEM education. Nationally, the Education Council (2015) set two goals. Goal 1 is to “ensure all students finish school with strong foundational knowledge in STEM and related skills” (Education Council, 2015, p. 5). Goal 2 is to “ensure that students are inspired to take on more challenging STEM subjects” (p. 5). Together, these goals set STEM education the task of building student interest and aspiration in STEM, and developing fundamental STEM skills for all students, as well as higher-level capabilities wherever possible. Victoria, the state where this study takes place, embraced these national goals and sets specific measurable targets against which its progress towards them could be assessed (DET Victoria, 2016a, 2016b). These included a 25 per cent increase in the proportion of Year 9 students achieving in the highest levels of mathematics as measured by NAPLAN, and a 33 per cent increase in the proportion of 15 year olds reaching the highest levels in scientific literacy, as measured by PISA (DET Victoria, 2016b). In addition, they set a target of a 25 per cent increase in the proportion of Year 10 students achieving in the highest levels for critical and creative thinking, as measured by a tool developed by the Victorian Curriculum and Assessment Authority (VCAA). These targets can be seen to align with Goal 1 of the national strategy. Other states have set targets aligning with Goal 2, including South Australia that is aiming for over an 8 per cent increase in the number of Year 12 students completing advanced mathematics, physics, and chemistry.

More recently, the Education Council (2018) has made its own recommendations for measuring the national performance in STEM education. Like the examples above from Victoria and South Australia, it proposes repurposing data currently collected at various jurisdictional levels, creating a “national STEM education dashboard” (Education Council, 2018, p. 16) to measure the impact of STEM education on raising student achievement and engagement, as well as addressing known equity issues. They suggest that data from PISA, TIMSS testing of Year 8 students, and Year 9 NAPLAN numeracy be used as indicators of
student STEM achievement. Elements of the dashboard measuring student engagement include Year 12 participation rates in advanced mathematics, biology, chemistry, physics, and Vocational Education and Training (VET) subjects in STEM fields. Equity would be tracked through the proportion of females enrolled in these subjects, and by the performance of Indigenous, low-SES, and remote students in the Year 9 NAPLAN numeracy test.

### 2.6.2 Measuring school STEM success

The measures suggested above are for gauging national or jurisdictional success in STEM education. This project explores whole school STEM success by systematically searching for rural schools with high STEM performance as sites for investigation. While there is a significant body of literature describing the characteristics of effective schools, there is limited literature making effective use of outcome measures to identify these schools (Wang et al., 2013). I was unable to find examples in the literature of such a methodical approach to identifying schools successful in STEM education to act as a model. There were also few examples of projects that have sought out rural Australian schools that were high performing in general. One example is the An Exceptional Schooling Outcomes Project (AESOP) which selected high performing schools, including rural schools, for case study using a combination of external examination performance, student achievement growth, and recommendations from organisations perceived to have valuable insight into school outcomes (Dinham, 2008). Unfortunately, the method used for selecting high performing schools in this project is not explained in detail in published material.

Given the limited available models, this study adopts the pragmatic approach of the various Australian jurisdictions of making use of data already routinely collected from schools to measure STEM success. The challenge then became to construct a valid measure of STEM success through appropriate selection and use of such data. Ideally, data used for this project would be generated by every school on an annual basis, capturing information about each cohort and allowing for more complete trend data to be examined. Further, the data needed to provide insight into each school’s success in fostering student engagement and achievement in the whole of STEM. A decision was made to use routinely collected senior STEM enrolment and achievement data, as, as argued in the next section, these data best meet these requirements.
Senior STEM subject enrolment as a proxy for STEM engagement

STEM engagement involves students being interested in STEM, perceiving themselves as capable STEM students, and seeing STEM industries as personally relevant (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B; Murphy, MacDonald, Wang, & Danaia, 2019; Panizzon & Westwell, 2009). The reasons students choose to study senior STEM subjects closely relate to the elements of engagement explored in the literature. Students cite personal interest and enjoyment as key factors informing senior science and mathematics subject selection (Goodrum et al., 2012; McPhan et al., 2008; Palmer et al., 2017). Self-efficacy in these subjects also has a significant impact on senior enrolment choices (Goodrum et al., 2012; Palmer et al., 2017) and has been shown to be closely linked to interest in science and technology (Potvin & Hasni, 2014). The perceived relevance of science and mathematics subjects to a student’s future career also influences student choice of senior subjects (Goodrum et al., 2012; McPhan et al., 2008). Relative to these aspects of engagement, the opinions and advice of parents, peers or teachers have been found to be less influential on subject choice in a study of Year 10 students from five schools in metropolitan Sydney, Australia (Palmer et al., 2017). Given this, a school attracting high enrolments in senior STEM subjects is likely to have succeeded in making STEM enjoyable, interesting, achievable, and relevant for their students. In short, school enrolment rates in senior STEM subjects give some good insight into how engaging a school’s STEM education program as a whole has been.

Senior STEM subject achievement as a proxy for STEM capabilities

Using senior school achievement in STEM subjects to gain insight into how well a school develops its students’ STEM capabilities is more fraught. STEM capabilities include the knowledge and skills of the individual disciplines, as well as interdisciplinary skills such as complex problem-solving, creative and critical thinking, and complex communication (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B; Murphy et al., 2020, see Appendix A). Assessment of senior STEM subjects typically focus upon disciplinary skills and knowledge, and use a range of assessment strategies including school-based and centrally administered examinations (Victorian Curriculum and Assessment Authority [VCAA], 2017). Further, the constraints of implementing such large scale and often standardised testing can mean these tests only give insight into a narrow skill set and limited aspects of the curriculum (Stacey et al., 2015; Morrison et al., 2015). Given this, it is difficult to argue that schools who have students who achieve well in senior STEM subject assessment necessarily have students
with strong STEM capabilities. Also, these assessments are only sat by students who have chosen to study senior STEM subjects, which represents a steadily decreasing proportion of the population (Office of the Chief Scientist, 2017). Not only does this miss a sizable proportion of the cohort, it is unlikely to be a representative sample of students, as students enrolling in senior science and mathematics studies report finding these subjects easier than their compatriots enrolled in non-STEM subjects (Goodrum et al., 2012; McPhan et al., 2008; Palmer et al., 2017). So a school with high achievement in senior STEM subjects has not necessarily equipped all students with strong STEM capabilities.

However, taking a pragmatic view, senior STEM subject achievement may be the best available measure for judging the relative effectiveness of a school’s STEM education program at fostering STEM capabilities. PISA tests for Mathematical and Science literacy (Thomson, De Bortoli, & Underwood, 2017) that are used as a measure of Australian students’ performance in STEM at national and state levels (Education Council, 2018; DET Victoria, 2016b), only sample approximately 20% of Victorian schools (Thomson, De Bortoli, & Underwood, 2017). Other tests, such as the international TIMSS testing (Thomson, Wernert, et al., 2017) and the nationally administered NAP Science (Connolly, 2017) and NAP ICT (ACARA, 2018) tests, are similarly inappropriate for use in this project due to sampling only some schools. Further, the former two measure student STEM capabilities too early to be a measure of whole-school secondary school STEM success, with TIMSS sampling Year 4 and 8 students, and NAP Science currently testing only Year 6 students. In addition to these limitations, PISA, TIMSS, NAP Science and NAP ICT are administered infrequently. NAPLAN annually assess the numeracy skills of students in every school (ACARA, 2017b), but this only tests one of the STEM disciplines, mathematics, and arguably a narrow skill set from that discipline (Stacey et al., 2015). Further, Australian students sit their last NAPLAN in May in Year 9, so the data it offers only provide insight into less than 50% of students’ secondary schooling. None of these assessments sample widely enough, frequently enough, late enough in schooling, or the disciplinary breadth required, to contribute to an effective measure of secondary school STEM success. Senior school STEM assessment data has none of these limitations. It is collected from all schools on an annual basis and assesses students at the conclusion of their school STEM education journey. In the absence of a better alternative, it is the best available achievement metric to use to judge relative school STEM success at developing student STEM capabilities.

This approach is not without its own limitations. Identifying STEM successful schools using the proposed metrics prioritises what is currently measured. Relying on such traditional
assessment tools may result in the impact of programs highly effective at developing student STEM capabilities being undervalued. For example, research into the impact of STEM integration on achievement tends to show less impact when standardised tests are used as a metric, but more when assessments tailored to the project are employed (Honey et al., 2014). A research approach that views effective STEM education in terms of measurable outcomes can only be as good as the assessment tools used. It will identify schools that are best at recruiting students to particular subjects, and preparing students to achieve well in the assessments used in these subjects, but not, perhaps, those schools best at building students’ STEM knowledge, skills, and dispositions.

2.7 Summary

This chapter began by exploring the research evidence for effective STEM education, then contrasting this to what the various Australian policies suggest will lead to effective STEM education. Combined, these elements will inform the analysis of findings from this study and allow the study’s third research question, “To what extent do the practices of high STEM performing rural schools reflect factors proposed in the literature as contributing to school STEM success?” to be comprehensively addressed.

The case was then built for this study’s focus on STEM education in rural Australian schools with an exploration of STEM education in rural contexts. It demonstrated that while the inequity between rural and metropolitan school performance is relatively well understood, and there is substantial conjecture as to what contributes to this gap, far less is understood about practices rural schools can employ to address this inequity. This provides the impetus to answer the study’s second research question, “What practices are believed to have contributed to the success of high STEM performing rural schools?”

The chapter went on to construct a justification for the research approach adopted in this study to meet this need. It argued that dominant modes of research into effective STEM education in Australia risk overlooking practices that may contribute to rural school STEM success, as they tend to explore practices previously promoted as contributing to effective STEM education, and be conducted at more readily accessible sites. Further, the dominant research emphasis has been on developing a thorough understanding of relatively short-term STEM education interventions, rather than exploring effective STEM education at the whole school level, despite an individual’s whole learning journey from early childhood to beyond adolescence being acknowledged as crucial to STEM learning. Combined, this built an
argument for the research strategy driving this study, one that uses school STEM performance to guide the selection of rural schools for research into whole school STEM success.

Finally, a literature base was outlined to support an argument for the content validity of the measures used to gauge the STEM performance of rural schools in Phase One of this study, in order to address the first research question of this study, “Which rural Victorian government schools are performing better than expected in STEM education?”

Ultimately, this literature review builds the case for the research presented in this thesis. This study focusses upon STEM education in rural schools, a known and significant issue in STEM education, however one attracting limited explicit attention from STEM education researchers and policy makers alike. Further, it explores the practices that cumulatively lead to whole-school STEM success, another area with a very limited research base. Finally, this study compares the practices that contribute to success in rural Victorian government schools, to those promoted by researchers and policy makers as leading to school STEM success. This tests the transferability of these STEM education practices into rural Australian school contexts, illuminating strengths and weaknesses of these notions of effective STEM education, relative to rural schooling.
3.1 Preamble
This research explored the practices of high STEM performing rural secondary schools in order to make findings that may be of value to those aiming to improve the STEM education practices of similar rural schools. Informed by the literature review presented in Chapter 2, this study was guided by two assumptions: 1. That there are some rural secondary schools that are relatively successful in STEM education; and 2. That the practices of these rural schools contribute to the STEM success of these schools. In order to answer the research questions posed on the basis of these assumptions, this study utilised a conceptual framework that draws together two key perspectives: 1. Appreciative Inquiry; and 2. The theory of Practice Architectures. As demonstrated in the previous chapter, much of the research into STEM education in rural contexts adopts a deficit view, investigating the poor performance of rural students in STEM disciplines. In contrast, this study adopts the strengths-based orientation of Appreciative Inquiry (Jarvis et al., 2016), investigating sites where rural schools are performing better than expected in STEM, in order to identify practices that may help to improve rural STEM education. Elements of the theory of Practice Architectures (Mahon at al., 2017) are used to identify and comprehensively describe these practices contributing to rural STEM success, as well as the factors that enable them.

This chapter provides an overview of Appreciative Inquiry and the theory of Practice Architectures. It then presents an explanation of how each has contributed to framing this study.

3.2 Appreciative Inquiry
This study assumed that while rural schools tend to do more poorly in STEM education than their metropolitan counterparts, there are some rural schools that perform better than expected. The contention is that by learning about the education practices of these relatively STEM successful rural schools, strategies for improving STEM education in similar rural contexts may be revealed. As such, this study adopted a strengths-based approach, borrowing elements of Appreciative Inquiry that has its foundations in organisational research and development (Reed, 2007), and is now finding expression in educational research (Bergmark & Kostenius, 2018; Giles & Bills, 2017; Jarvis et al., 2016).
Strengths-based approaches aim to identify and build upon individual, social, and/or organisational strengths to facilitate positive change, as opposed to deficit approaches that focus on problems or shortcomings. Deficit approaches are associated with a range of negative effects. In social work, a focus on problems and weaknesses impacts the way clients are perceived, the way clients perceive themselves, and even the way resources are allocated (Saleebey, 2012). In psychology a focus on difficulties can lead to clients being seen by themselves and others as a “cluster of deficits” (Bozic, 2013, p. 19). A deficit approach to organisational leadership can result in distrust and defeatism (Ghaye et al., 2008), potentially leading to a “degenerative spiral” (Grant & Humphries, 2006, p. 403). In education, deficit views are associated with disengagement, low motivation, beliefs of inferiority, and lower expectations (Sharma, 2016). As section 2.5 of this thesis demonstrates, a deficit view is prominent in research into rural STEM education. This study adopted a strengths-based approach as a positive alternative to this dominant orientation to research into rural STEM education.

3.2.1 How Appreciative Inquiry shapes this study
The strengths-based model informing this study is Appreciative Inquiry (Reed, 2007). Appreciative Inquiry is an approach to organisational research that assumes “in every society, organisation, or group, something works” (p. 18), and that an understanding of these strengths can inform future improvements. This assumption was key to this study. Across the Victorian DET schools, as with schools throughout Australia, rural students are outperformed in STEM education by their metropolitan counterparts (Murphy, 2018a, 2018b, 2019a). However, this study assumed there were rural Victorian schools where “something works”, where students had high participation and achievement in STEM subjects, despite their location. Further, this study assumed that the practices of these schools where “something works” had contributed significantly to the schools’ STEM success, thus providing insights that might inform the improvement of STEM education in other rural schools. Following this rationale, this study sought out, and investigated the practices of, high STEM performing schools.

Appreciative Inquiry also informed the way practices at the high STEM performing rural schools were investigated. Appreciative Inquiry adopts a positive orientation to enquiry, inviting participants to explore achievements, rather than to examine problems, as a way to engage participants for longer and more deeply (Reed, 2007). Giles and Bills (2017) suggest a positive orientation is effective in researching schools, claiming Appreciative Inquiry
generates “extensive qualitative data from the teachers and leaders, offering an opportunity for deep interpretive analysis” (p. 120). Appreciative Inquiry also draws on a social constructivist orientation, where individuals construct personal understandings of the world, and those understandings impact the way they act and think (Reed, 2007). At the same time, individuals and groups are seen as builders of their world, deliberately shaping particular elements while neglecting others. This constructivist orientation requires the investigation of the contributions and perspectives of various actors in and around an organisation in order to construct a comprehensive understanding of the strengths of that organisation (Bergmark & Kostenius, 2018). Reed (2007) suggests that participants in Appreciative Inquiry should be chosen to represent the views and experiences from multiple levels and perspectives of the organisation. This study was informed by Appreciative Inquiry’s positive and constructivist orientations. It assumed that school community members, as both actors within, and builders of, their world, have legitimate and valuable insights into practices that may have contributed to their school’s STEM success.

3.2.2 Aspects of Appreciative Inquiry not adopted
In aligning this study with Appreciative Inquiry, it is important to note that there are elements of Appreciative Inquiry the study did not adopt. First, Appreciative Inquiry is seen as generative of positive change (Reed, 2007), whereas the intention of this research was to explore factors that have contributed to rural school STEM success, not to plan for any future change. Second, Appreciative Inquiry research is seen as communal, involving collective interaction and exploration (Reed, 2007). The communal nature of this study was minimal, with the investigation being constructed by the researcher, and participants generally interviewed individually. In fact, as explained in the Chapter 4: Methodology, this was viewed as necessary for the validity and reliability of the study’s findings.

3.2.3 Appreciative Inquiry’s suitability for this study
There has been only limited evaluation of Appreciative Inquiry as a research method (Grant & Humphries, 2006). It has been critiqued for potentially producing a sanitized view through its positive orientation (Reed, 2007). It has been suggested that Appreciative Inquiry ignores issues or problems (Coghlan et al., 2003). However, others argue that Appreciative Inquiry does not overlook problems, and that, in fact, its positive orientation can mean issues and weaknesses are more likely to emerge (Patton, 2003). Golembiewski (2000) suggests that Appreciative Inquiry’s positive lens discourages analysis and critical inquiry. Van der Harr
and Hosking (2004) counter that Appreciative Inquiry has the potential to facilitate critical inquiry as its underlying premises focus attention on the construction of world views, identity, and actions. Proponents of Appreciative Inquiry respond to criticisms by suggesting that Appreciative Inquiry is most appropriate for research aimed at identifying strengths rather than problems (Rogers & Fraser, 2003). Given this study’s aim to identify strengths through an exploration of practices possibly contributing to rural school STEM success, and its interest in the construction of these practices, it was appropriate to employ aspects of Appreciative Inquiry.

3.3 The theory of Practice Architectures
This study also draws on the theory of Practice Architectures to contribute rigor to the analyses and to further mitigate against the concerns about Appreciative Inquiry generating a naïve view of phenomena. In line with Appreciative Inquiry, in this study schools were viewed as complex, socially constructed organisations, where a complex interplay of activities by teachers, educational leaders, students, and parents have contributed to a school’s STEM education performance. The theory of Practice Architectures (Mahon et al., 2017) guide the exploration of these activities, and the factors that enable them.

3.3.1 How the theory of Practice Architectures shapes this study
Informed by the theory of Practice Architectures, this study viewed a practice as a socially recognisable activity that involves distinctive actions (doings), understood through characteristic discourses (sayings), enacted by actors that relate to each other and the wider world in characteristic ways (relatings) (Kemmis et al., 2014; Rönnerman & Kemmis, 2016). The theory of Practice Architectures holds that these three elements of a practice, sayings, doings, and relatings, are interconnected and “hang together” (p. 95) in a distinctive form (Rönnerman & Kemmis, 2016). For example, a recognisable practice of STEM education might be project based learning (PBL) (Capraro & Slough, 2013). The doings of PBL, as activities of consumption or production (Kemmis & Grootenboer, 2008), might include collecting data, trialing solutions to problems, or constructing models. The sayings of PBL, as activities of communication (Kemmis & Grootenboer, 2008), might include discussion with peers, teachers and experts, researching through websites and textbooks, or presenting findings in a range of forms. The relatings of PBL, as activities of social connection (Kemmis & Grootenboer, 2008), might include students collaborating with significant autonomy, and teachers adopting the role of facilitator. The doings, sayings and relatings of
practices are inseparable (Mahon et al., 2017). In the practice of PBL, discussion with peers is essential for collaboration, a degree of autonomy is a prerequisite for problem solving, and the collection of data are necessary to communicate findings. This study viewed all practices of school STEM education as similarly composed of these three, inseparable elements. By examining all three of these elements, practices that may have contributed to each school’s STEM success were identified and comprehensively described.

According to the theory of Practice Architectures, practices cannot be understood merely through an examination of sayings, doings, and relatings (Rönnerman & Kemmis, 2016). It is also necessary to understand the practice architectures that prefigure them. Practice architectures are composed of three corresponding arrangements; cultural-discursive arrangements, material-economic arrangements, and social-political arrangements (Kemmis et al., 2014). Like the three elements of practice, these arrangements interact with, and impact upon, each other. Cultural-discursive arrangements directly shape sayings and include the traditions, theories, and jargon of education. The forms of language and communication available, and the understandings shared with other educators at a school, shape the saying aspects of practices. Material-economic arrangements most directly influence doings. These structures include both products and the processes of production, from school buildings, staffing, and classroom resources, to school budgets, timetables, and unit plans. Socio-political arrangements impact upon relating aspects of practices. These arrangements are comprised of social networks and power relationships, and shape what are acceptable or expected interactions with students, parents, colleagues, leadership, and so on, at the school. It is important to note that not only do practice architectures pre-figure practices, practices themselves shape practice architectures (Kemmis et al., 2014). Sayings can overtime become traditions, doings can have material impacts, and relatings can alter social networks. These relationships between the elements of practice and associated arrangements are summarised in Figure 1. In this study, the arrangements impacting STEM education practices were explored to build a fuller understanding of the practices leading to the STEM success of the rural schools studied. Exploring the sayings, doings and relatings of a practice only identifies a practice’s presence and features. An exploration of practice architectures enabling these practices is necessary to understand their form and execution.
The study involved visiting schools in 2018 to seek evidence of practices that led to the high STEM participation and achievement of schools identified through Victorian Certificate of Education (VCE) data collected in 2014, 2015, and 2016. As such, it attempted to look back in time at the STEM education practices, and the practice architectures that shaped them, that resulted in students at the case schools choosing to study STEM subjects in VCE and achieving well in these subjects. Adopting elements of the theory of Practice Architectures to form the conceptual framework for this study supported this backward looking approach, as the theory of Practice Architectures suggests that practices leave evidence of their implementation in various forms. Kemmis et al. (2014) states:

The practice takes up sayings, doings and relatings already to be found in the site, orchestrates and engages with them, and leaves behind in the setting particular kinds of discursive, physical and social traces or residues of what happened through the unfolding of the practice. These traces or residues are left not only in participants’ memories and interactional capacities but also in the practice itself as a site for sociality. Some of these residues become part of the practice architectures of the setting and are newly encountered by others who subsequently inhabit it. (p. 34)

This suggests that there are a range of sources to be utilised in a study such as this one to investigate the practices that led to each school’s STEM success. Teachers involved in the execution of the practices had both memories of those practices, and also had been impacted.
by their experience of those practices. Similarly, artifacts from each school from that time provide insight into practices contributing to STEM success, such as the products and descriptions of practices (for example, student work, reports and media), as well as evidence of the arrangements that shaped them (for example, policies, timetables, and facilities). The practices were enabled by practice architectures that are likely still in place, and thus similar practices are likely still enacted. Further, practice architectures can be seen as sayings, doings, and relatings that have become institutionalised (Kemmis, 2008). By using particular modes of communication, acquiring, producing, or consuming particular resources, or establishing and maintaining certain relationships, educators contribute to the construction of practice architectures that continue to shape current activities. Thus, traces of the practices contributing to STEM success in the past may be evident in contemporary practices, and the practice architectures that shape these practices, at each school. Given this, the perspectives of current students, and teachers new to the school offered valid insights gained from ‘inhabiting’ these practice architectures.

3.3.2 Aspects of the theory of Practice Architectures not adopted
The conceptual framework guiding this research draws on only some aspects of the theory of Practice Architectures. As already flagged, given the appreciative inquiry orientation of the study, its primary interest is on the ways practice architectures have enabled, rather than constrained, effective STEM education practices. Further, the definition of practice adopted for this research is somewhat broader than that proposed in the theory of practice architectures, where it uses the notion of the “project of a practice” that:

- encompasses (a) the intention (aim) that motivates the practice, (b) the actions (interconnected sayings, doings and relatings) undertaken in the conduct of the practice and (c) the ends the actor aims to achieve through the practice (although it might turn out that these ends are not attained) (Rönnerman & Kemmis, 2016) p. 95)

This study’s interest is in the practices, and the architectures that enabled those practices, which contributed to each school’s high participation and achievement in senior STEM classes. As such, the ends are ascribed, whether or not the educators at the site were aiming for that result for their practice. Similarly, the intention motivating the practice was not a focus of this research. While it may be that STEM education success in rural schools has been motivated by conscious intent, it is not a necessary condition to warrant actions at
rural schools being considered as practices in this study. So, this study adopts a wider view of practice than the theory of Practice Architectures, where a practice is comprised of the actions used to conduct a practice, in the presence or absence of an aligned intent motivating those actions or particular ends being aimed for by the actors carrying them out.

The theory of Practice Architectures is positioned as a theoretical resource, an analytical resource, and a transformational resource (Mahon et al., 2017); however, this study used it only as an analytical resource. As an analytical resource, the theory of Practice architectures does not prescribe a particular methodology, but rather focusses research attention on the sayings, doings and relatings involved in practices, as well as arrangements that make them possible (Mahon et al., 2017).

3.3.3 The theory of Practice Architectures suitability for this study

The theory of Practice Architectures is just one practice theory in a highly contested space (Schatzki, 2005). Common to practice theory is a focus upon shared activities, and the dependence of these activities on shared understandings, as well as the inculcation of these understandings to maintain practices. What is contested is what more than shared understanding is required to explain practice. Some theorists argue for a simple conception of practice, where shared activity results merely from individuals sharing the same skill set, whereas others present more complex models of influence on practice (Barnes, 2005). Practice Architecture offers a complex theorisation of practice, identifying, as it does, interacting cultural-discursive, material-economic, and social-political arrangements, and adding relatings activities to the activities of sayings and doings already identified by Schatzki (Mahon et al., 2017). The theory of Practice Architectures is positioned in the literature as a “lens for exploring learning” (Mahon et al., 2017, p. 18). It has been used to explore education in a range of contexts, from early childhood centres through to tertiary institutions, in primary school literacy and numeracy lessons through to lectures for health professionals and vocational education and training (Mahon et al., 2017). Given this, it was selected as a suitable practice theory to draw from for constructing the conceptual framework for this project.

3.4 The conceptual framework

Combined, the elements of Appreciative Inquiry and the theory of Practice Architectures discussed above provide a conceptual framework that focusses attention on practices contributing to STEM success in rural schools, facilitates a thorough interrogation of these
practices and the arrangements that enable them, and emphasises the contributions and perspectives of teachers and students.

Appreciative Inquiry and the theory of Practice Architectures share significant similarities. Appreciative Inquiry sees social reality as co-constructed through language (Jarvis et al., 2016), and language inseparable from action and understanding (Grant & Humphries, 2006). The theory of Practice Architectures seeks to understand social reality by examining practices viewed as cooperative human activities comprised of inextricably linked sayings, doings and relatings (Mahon et al., 2017). Further, Appreciative Inquiry conceives organisations as an outcome of individual and group interactions with cultural, economic, social and political factors (Grant & Humphries, 2006). The theory of Practice Architectures views practices as enabled and constrained by cultural-discursive, material-economic, and socio-political arrangements (Mahon et al., 2017). Finally, both Appreciative Inquiry and the theory of Practice Architectures adopt a site specific view. Appreciative Inquiry sees the form of an organisation as peculiar to its temporal, historical and cultural context (Reed, 2007). The theory of Practice Architectures sees practices as situated, shaped by the history and resources that exist at sites at a particular time (Kemmis et al., 2014). These similarities allowed both theories to be drawn upon to create a cohesive conceptual framework for this project.

Aspects of Appreciative Inquiry and the theory of Practice Architectures provided the conceptual framework that guided this research in looking for practices contributing to STEM education success at each school, as illustrated in Figure 2. Informed by Appreciative Inquiry, the project began with the assumption that “something works” resulting in some rural schools having relatively high performance in STEM education. This was the interest of the study, defining the research space, as represented by the outer-border of the figure. Figure 2 shows the three interrelated components of the conceptual framework that are part of the “something” that “works” in a high STEM performing school: the practices that contributed to success; the practice architectures that enabled those practices; and the teachers and students who enacted the practices, and constructed and inhabited the practice architectures. As already noted, there may be other factors contributing to a school’s STEM success, however Appreciative Inquiry’s positive orientation focuses attention on contribution made by the practices of the school.
Figure 2

A conceptual framework for investigating STEM success in a school.

Figure 2 highlights the elements from the theory of Practice Architectures that provided the structure necessary to identify and describe practices that contributed to school STEM success, as well as the practice architectures that enabled these practices. The conceptual framework draws attention to what educators and students at these high STEM performing schools did (doings), how they communicated (sayings), and how they related to one and other (relatings), as part of STEM education practices. Further, it requires investigation of the language, norms and traditions (cultural-discursive arrangements), the resources and resource management (material-economic arrangements), and the social arrangements and power dynamics (socio-political arrangements), which enabled these practices. The vertical arrows in Figure 2, one pointing from practices to practice architectures, the other in the opposite direction, is a reminder that while practice architectures enable practices, they are also shaped by them, as practices become institutionalised. As such, the arrangements of practice architectures themselves are seen to hold evidence of practices that may have contributed to a school’s STEM success.
Finally, the combination of elements of Appreciative Inquiry and the theory of Practice Architectures emphasises the contribution of teachers, school leaders, and students to the high STEM performance of a school. Teachers, school leaders, and students were seen as key enactors of the practices contributing to STEM success, builders of the arrangements that enabled these practices, and inhabitants of the resulting architectures, as indicated by the horizontal arrows in Figure 2. As such, they possess significant insight into the contributors to a school’s STEM education performance. Importantly, Appreciative Inquiry suggests that each individual will have formed their own interpretation of the world, prompting the researcher to seek insights from a range of members of each school’s community (Bergmark & Kostenius, 2018).

3.5 Summary
Aspects of Appreciative Inquiry (Reed, 2007), and the Theory of Practice Architecture (Mahon et al., 2017) have been used to construct a conceptual framework to guide this research. The first research question of this study, “Which rural Victorian government schools achieve relative success in STEM education?” is addressed through the adoption of the Appreciative Inquiry assumption that in every organisation “something works”. In this case, the organisation is the Victorian DET, and the “something” that “works” are those rural schools performing better than expected in STEM education.

In responding to the second research question, “What practices are believed to have contributed to the success of these high STEM performing rural schools?” the perspectives of teachers, leaders and students at these schools were viewed as providing insights into both practices and factors that shaped those practices. Appreciative Inquiry suggests that actors construct their own personal understandings of their world, thus it is important to seek the perspectives from a wide range of teachers, as well as the perspectives of school leaders and students.

Finally, in order to address the third question of this study, “To what extent do the practices of high STEM performing rural schools reflect factors proposed in the literature as contributing to school STEM success?” a comprehensive description of each practice believed to have contributed to STEM success was required. The sayings, doings, and relating activities of each practice, as well as the practice architectures that enabled the STEM education practices at each school need to be described. This required drawing on the memories and perspectives of the various members of the school community, in line with Appreciative Inquiry, as well as seeking further evidence of practices and practice
architectures in the school’s displays, student work, facilities, resources, policies, timetables, and other artefacts.
Chapter 4: Methodology

4.1 Preamble
This chapter describes the methodology for the two phases that made up this study. Phase One repurposed routinely collected school level data to identify a set of high STEM performing rural Victorian government schools to answer the first research question of the project, namely:

1. Which rural Victorian government schools achieve relative success in STEM education?

Phase Two was a multi-case study of a purposive sample of these high-STEM performing rural schools to address the study’s second and third research questions:

2. What practices are believed to have contributed to the success of these high STEM performing rural schools?

3. To what extent do the practices of high STEM performing rural schools reflect factors proposed in the literature as contributing to school STEM success?

The chapter begins with an overview of the study’s design. It then describes the methods of data analyses used in Phase One, including considerations of validity. An overview of the selection and contexts of the sites selected for Phase Two is presented, followed by a description of the techniques used for data collection and analysis for each site, as well as the analytical strategy used to draw the findings together for the multi-case study. Issues of reliability and validity for Phase Two are considered, and the ethical management of the project is outlined.

4.2 Research design overview and rationale
This study adopted an explanatory sequential mixed methods design (Creswell, 2017). Explanatory sequential mixed methods uses qualitative approaches to attempt to explain quantitative results. Quantitative data is first analysed and specific results that require explanation are identified, before qualitative techniques are used to determine this explanation. In this study, Phase One used quantitative secondary data provided by the DET to explore the variation in school performance in STEM education by socioeconomic status and school location. Through analysis of this DET data, Phase One demonstrated that some rural schools consistently had higher enrolments and achievement levels in STEM subjects than schools of similar socioeconomic status, a finding not evident in the extant research.
literature. Phase Two used qualitative techniques to seek an explanation of how these rural schools achieved their relatively high STEM education performance. Phase Two involved case studies of four relatively high STEM performing rural schools through the collection of primarily qualitative data from these schools, including: interviews with the schools’ principals, educators, and students; school documents; and images of school resources and facilities. These data were analysed with a view to illuminating practices that had contributed to their relative STEM success. This explanatory sequential mixed methods design is illustrated in Figure 3.

**Figure 3**

*The explanatory sequential mixed methods research design used in this study*

The methodological approach taken in this study can be viewed as reflective of a pragmatic paradigm (Cohen et al., 2011; Onwuegbuzie & Leech, 2005). Rather than being driven by an overarching philosophy or methodological purity, pragmatic approaches are framed by practical concerns and considerations (Denscombe, 2008). The study’s research questions drove the development of the study’s mixed methods approach. To respond to the
first research question, ‘Which rural Victorian government schools achieve relative success in STEM education?’ required the consideration of the STEM education performance of 286 schools to determine first if there was sufficient variation between rural schools for any schools to be viewed as relatively more, or less, successful in STEM education, and, if so, to then identify those rural schools that were relatively successful. This task is most suited to quantitative techniques.

However, a qualitatively driven case study approach was well suited to providing an explanation to why these rural schools were relatively successful in STEM education, answering the study’s second research question ‘What practices are believed to have contributed to the success of high STEM performing rural Victorian government schools?’ and providing the empirical evidence required to respond to the third research question, ‘To what extent do the practices of high STEM performing rural schools reflect factors proposed in the literature as contributing to school STEM success?’ Case study designs allow the exploration of a phenomenon (in this case, STEM success) in its real-world context (in this case, the rural schools identified through Phase One), where the phenomenon and context are difficult to distinguish (Reed, 2007). Case study approaches are suitable where the researcher has minimal influence over the events studied, and the focus is on recent events in context (Yin, 2014). They allow for deep exploration of complex phenomena situated in their real-world setting (Crowe et al., 2011). Further, case study is particularly suited for generating accounts of education practices and is a powerful mechanism for informing future practices (Miles, 2015). Given all this, the mixed method design developed is a good pragmatic match for meeting the aims and addressing the questions of this study.

4.3 Study Context – Victoria, Australia

This study was concerned with STEM education success in rural Victorian government schools offering a secondary curriculum. In Victoria, as elsewhere in Australia, students typically commence primary school at age five in the foundation year. Primary school continues for seven years until Year 6. Year 7 marks the transition to secondary school. Victorian schools follow a common curriculum until the end of Year 10, when students are usually 16 years old. In Years 11 and 12, the Victorian Curriculum provides students with a choice of two senior certificates of education: the Victorian Certificate of Education (VCE), or the Victorian Certificate of Applied Learning (VCAL). The vast majority of students completing Year 12 study the VCE. The VCE is designed to be completed over 2 years, and is made up of semester long units of study, with Unit 1 and Unit 2 studies benchmarked at a
Year 11 level and Unit 3 and Unit 4 studies benchmarked at a Year 12 level (VCAA, 2017). Students are awarded the VCE after completing a minimum of 16 units, including three English units and three Unit 3-4 sequences in addition to English. However, students typically complete more units than this, with most schools encouraging students to take 12 units at Year 11 level and 10 units at Year 12 level. Year 11 level units are assessed only as satisfactory or unsatisfactory. Year 12 level units allow students to earn a study score by completing a combination of school-based and external assessments, for Year 12 level units. These study scores are used to determine a student’s Australian Tertiary Admission Rank (ATAR) which Australian tertiary institutions use as a key element of their candidate selection process for most of their courses. VCE participation and achievement data were used in this project to identify STEM successful schools in Phase One. Some students study the VCAL, a certificate focused on providing students with vocational skills and not on providing an ATAR.

As discussed in Section 1.7, in this thesis, the term ‘STEM subject’ is used to describe any subject designed to deliver content from one or more of the STEM disciplines, so is used to refer to conventional mathematics, science, technologies and engineering subjects, as well as subjects teaching any combination of these four. This is an inclusive definition of STEM education, emphasising participation and achievement in any STEM subjects, rather than privileging participation and achievement in more advanced STEM subjects as some STEM education policies do (Murphy et al., 2019). This definition is useful as STEM has no distinct identity in the Victorian Curriculum from Foundation to Year 12. There is prescribed content from Foundation to Year 10 for Science, Digital Technology, Design and Technology, and Mathematics, and no content is identified as ‘Engineering’ (VCAA, 2019). Schools have the freedom to deliver this content through subjects designed as they see fit, however, Victorian schools are directed to focus on Mathematics from Foundation to Year 2, broadening this focus to emphasise both Mathematics and Science from Years 3 to 8 (VCAA, 2015). Years 9 and 10 are seen as providing a breadth of experience in preparation for senior secondary study in Year 11 and 12. In VCE, schools must deliver the STEM disciplines through subjects with prescribed content that follows conventional disciplinary boundaries. These subjects are classified either as Sciences, Technologies, or Mathematics (VCAA, 2017) and are listed in Table 2. In this thesis, these are referred to as the VCE STEM subjects. It is worth noting that this list includes Psychology, a subject that might not be regarded by some as a STEM subject, but, as a science, is treated as a STEM subject in this study.
As can be seen in Table 2, there is no ‘Engineering’ category of subjects in the VCE, however ‘Systems Engineering’ is part of the Technologies suite of subjects. The Science and Technology subjects are shaped around disciplinary identities, while the mathematics subjects are design to meet students’ mathematical aspirations (VCAA, 2016). Foundation Mathematics is for students not intending to study mathematics at a Year 12 level. General Mathematics and Further Mathematics are designed to be widely accessible. Both involve the study of non-calculus based topics such as geometry, statistics and algebra. Mathematical Methods involve more advanced mathematics, including the study of calculus, probability and statistics. Specialist Mathematics are the most advanced mathematics subjects offered in the VCE. They are designed to be taken in conjunction with Mathematical Methods.

<table>
<thead>
<tr>
<th>Category</th>
<th>Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>Biology - Units 1-4</td>
</tr>
<tr>
<td></td>
<td>Chemistry - Units 1-4</td>
</tr>
<tr>
<td></td>
<td>Environmental Science - Units 1-4</td>
</tr>
<tr>
<td></td>
<td>Physics - Units 1-4</td>
</tr>
<tr>
<td></td>
<td>Psychology - Units 1-4</td>
</tr>
<tr>
<td>Technologies</td>
<td>Computing (previously Information technology) – Units 1&amp;2</td>
</tr>
<tr>
<td></td>
<td>Computing: Informatics (previously IT applications) – Units 3&amp;4</td>
</tr>
<tr>
<td></td>
<td>Computing: Software development – Units 3&amp;4</td>
</tr>
<tr>
<td></td>
<td>Algorithmics – Units 3&amp;4</td>
</tr>
<tr>
<td></td>
<td>Product design and technology – Units 1-4</td>
</tr>
<tr>
<td></td>
<td>Food and technology – Units 1-4</td>
</tr>
<tr>
<td></td>
<td>Agricultural and horticultural studies – Units 1-4</td>
</tr>
<tr>
<td></td>
<td>Systems engineering – Units 1-4</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Foundation Mathematics – Units 1&amp;2</td>
</tr>
<tr>
<td></td>
<td>General Mathematics – Units 1&amp;2</td>
</tr>
<tr>
<td></td>
<td>Further Mathematics – Units 3&amp;4</td>
</tr>
<tr>
<td></td>
<td>Mathematical Methods – Units 1-4</td>
</tr>
<tr>
<td></td>
<td>Specialist Mathematics – Units 1-4</td>
</tr>
</tbody>
</table>
extending its content to look at topics such as complex numbers, vectors, and statistical inference. It should be noted that schools are not required to make all or any of these STEM subjects available to their students, nor are students required to study any STEM subjects as part of their VCE (VCAA, 2017).

In Victoria, the majority of students are educated in government schools. More than half of secondary students attended government schools, with approximately a fifth of students attending catholic schools and independent schools respectively (DET Victoria, 2019). In 2016 in the Victorian government education system 309,714 (78%) of students attended schools in major city areas, 71,011 (18%) in inner regional areas, and 17,381 (4%) in outer regional or remote areas (DET Victoria, 2016c). In this study, schools in these inner regional, outer regional and remote areas, were classified as ‘nonmetropolitan schools’. The relative STEM success of each of these schools was assessed through Phase One of this study.

4.4 Phase One – Identifying high STEM performing schools

Phase One, in line with this study’s conceptual framework informed by Appreciative Inquiry, assumed that there were relatively high STEM performing schools and set out to identify these schools. This phase adopted a pragmatic, outcomes view of STEM education success. In Victoria, and Australia wide, STEM education strategies aim to increase student participation and achievement in senior secondary school STEM subjects (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). Given this, Phase One repurposed enrolment and achievement data routinely collected from all Victorian government schools to search for schools that consistently had relatively high enrolments in Year 11 STEM subjects, relatively high enrolments in Year 12 STEM subjects, and relatively high achievement in VCE STEM subjects, across the years 2014, 2015, and 2016.

A set of three criteria was used to compare the STEM performance of Victorian government schools offering the VCE. These criteria, herein referred to as the School STEM Success Criteria (SSSC) are:

1. Mean school enrolment proportions in STEM subjects at Year 11 level across 2014, 2015, and 2016;
2. Mean school enrolment proportions in STEM subjects at Year 12 level across 2014, 2015, and 2016; and
The data for this study was used to test the construct validity of these criteria for measuring STEM education success, as well as to apply these criteria to identify a set of high STEM performing rural schools as potential participants in Phase Two. As shown in Section 2.2.2 of the literature review, socioeconomic status (SES) and location are known to impact on both enrolments and achievement in STEM. Given this, the criteria were applied to schools of similar location and SES to judge their relative STEM performance.

4.4.1 Establishing the content validity of the school STEM success criteria
The validity of a method is the degree to which it measures what it claims to measure, with the aim being to maximise validity and minimise invalidity (Cohen et al., 2011). Content validity is the extent to which the selected variables are appropriate for measuring the phenomena of interest (Muijs, 2004). Section 2.6 of the literature review provides strong evidence for the content validity of the school STEM success criteria. As argued in Section 2.6, the almost universally held goal for STEM education is to engage students and build their STEM capabilities (CEDEFOP, 2014; Education Council, 2015; National Science and Technology Council, 2013; The Parliamentary Office of Science and Technology, 2013). Enrolment proportions in senior STEM directly measure school success at increasing participation in senior STEM studies, a target set for STEM education by many Australian jurisdictions (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). It is also arguable that enrolment proportions reflect the general success of a school in engaging students in STEM, given that an interest in, and valuing of, STEM is a common reason students choose to study STEM subjects in senior years (Goodrum et al., 2012; McPhan et al., 2008; Palmer et al., 2017). Further, student achievement in STEM subjects is closely linked to student interest in STEM (Potvin & Hasni, 2014), so a school attracting strong STEM enrolments into senior STEM is also likely to be building the STEM capacity of its students. VCE STEM achievement levels obviously measure STEM achievement, but only of students who have chosen to study senior STEM subjects. Unfortunately, there was no data available from DET to measure the general STEM literacy of the student population of a school. Despite this, the combination of the three criteria to judge school STEM success is felt to have the best achievable content validity using the data available.

4.4.2 Secondary data collection
Phase One was completed from October 2017 to January 2018, using school-level demographic data and VCE enrolment and achievement data. It captured data from every
Victorian government school offering a VCE program in 2014, 2015 and 2016. These data were provided by the Performance and Evaluation Division of the DET Victoria (DET) in a de-identified form, with an agreement that the STEM successful rural schools would be re-identified for the researcher at the conclusion of Phase One. Data were provided at a school level granularity and are summarised in Table 3.

In order to maintain the anonymity of schools, location classifications used by the DET were provided rather than more accurate postcodes. These classify schools according to the location classification of their local government areas. The state of Victoria is comprised of 81 local government areas, 32 classified as major city, 32 as inner regional, 14 as outer regional, and only 3 as remote (DET Victoria, 2016c). As discussed in Section 1.7, in this study schools in the major city local government areas were classified as ‘meteoropolitan schools’, and all other schools were classified as ‘non-meteoropolitan schools’.

Table 3

<table>
<thead>
<tr>
<th>Data acquired from DET about each Victorian School delivering a VCE program</th>
</tr>
</thead>
<tbody>
<tr>
<td>De-identified school code:</td>
</tr>
<tr>
<td>School Location Classification:</td>
</tr>
<tr>
<td>School Student Family Occupation and Education Index (SFOE)</td>
</tr>
<tr>
<td>VCE enrolments:</td>
</tr>
<tr>
<td>Median STEM Study Scores:</td>
</tr>
</tbody>
</table>

Each school’s Student Family Occupation and Education (SFOE) index was acquired as a measure of socio-economic Status (SES). The SFOE is calculated by DET using parent occupation categories and education levels provided by parents upon enrolment at the school (DET Victoria, 2017). SES is known to impact the achievement and engagement of students in STEM education (Elsworth et al., 1999; Lyons & Quinn, 2010; McPhan et al., 2008; Thomson, De Bortoli, & Underwood, 2017; Thomson, Wernert, et al., 2017), so the SFOE index was required to allow the comparison of schools serving communities of similar SES. The SFOE allocates each school a score from 0 (the highest SES) through to 1 (the lowest SES) (DET Victoria, 2017). Given this, it is a measure of disadvantage, where schools with
higher SFOE scores have more students from less advantaged backgrounds. Given the convention is for SES measures to indicate advantage, with the higher the SES the more advantage, the SFOE score of each school was subtracted from 1 to produce an SES score that aligns with this convention for use in analysis.

These data were chosen in order to facilitate the identification of high STEM performing schools relative to schools of similar location and SES. STEM performance was compared by considering both student enrolment in Years 11 and 12 level VCE STEM subjects, as well as student performance in Year 12 level VCE STEM subjects.

4.4.3 Secondary data analysis

For the purposes of seeking STEM successful schools relative to similar schools, schools were categorised into one of eight like-school groups, as shown in Table 4. They were first categorised by location, as either metropolitan or non-metropolitan schools. Then each location was divided into quartiles according to their SES score, with the first quartile (Q1) for a location including the 25% of schools with the lowest SES score, and the fourth quartile (Q4) for a location including the 25% of schools with the highest SES score.

Schools from the same like-school groups were compared using three outcome variables, each aligned to one of the three school STEM success criteria: average STEM enrolment proportion at Year 11, average STEM enrolment proportion at Year 12, and average STEM achievement Level.

Table 4

<table>
<thead>
<tr>
<th>Location</th>
<th>Metropolitan Schools (N= 164)</th>
<th>Non-metropolitan Schools (N= 122)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SES quartile</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Like-school group</td>
<td>MS1 (N= 41)</td>
<td>MS2 (N= 41)</td>
</tr>
</tbody>
</table>

Enrolment Proportions: Enrolment Proportions for each STEM subject were calculated for each school delivering that subject by dividing the number of enrolments in a particular STEM subject by the total number of VCE enrolments at that particular year level and then averaging this result across the three years (2014-2016). Two composite variables were then calculated to assess school STEM success against the school STEM success
criterion 1 and 2 described in Section 4.4. The average STEM enrolment proportion at Year 11 was calculated for each school by taking the mean of the enrolment proportions for each STEM subject run by the school at the Year 11 level. Similarly, the average STEM enrolment proportion at Year 12 was calculated using the enrolment proportions of individual STEM subjects at the Year 12 level. Thus, the STEM enrolment proportions were the proportion of total VCE enrolments at a particular year level accounted for by the enrolments in STEM subjects offered at each school. It should be noted that it is likely that many students were enrolled in more than one STEM subject, however there is no way to identify this in the data used for this analysis.

**Achievement Levels:** Study scores are only available for the Year 12 subjects in VCE so Achievement Levels could only be calculated for each Year 12 STEM subject. Achievement levels were calculated for each individual STEM subject where a school ran that subject in all three years (2014, 2015 and 2016) by averaging the median school Year 12 study score in that subject from each of the three years. Study scores have been standardised by the VCAA to allow them to be compared from school to school and year to year. This is done by first ranking each student’s performance against all others in that subject in that year. Students are then allocated study scores according to their rank so that the distribution of scores is normalised, with a maximum of 50, a set mean of 30, and standard deviation of 7 (VCAA, 2017). Given this, it is appropriate to calculate an average score for a STEM subject across the three years. A composite variable was calculated to assess STEM success against school STEM success criterion 3, described in Section 4.4, by taking the mean of all the achievement levels in STEM subjects for each school.

**4.4.4 Establishing the construct validity of the school STEM success criteria**

**Construct validity** “concerns the extent to which a particular measure… conforms to the theoretical context in which it is located” (Cohen et al., 2011, p. 188). The manner in which the school STEM success criteria conforms to its theoretical context was explored in several ways. First, if STEM engagement and achievement are significantly impacted upon by school level factors as promoted in the literature, it would be expected that STEM enrolment proportions and achievement levels do not vary greatly from year to year. The within-school variation of mean STEM enrolment proportions in Year 11, enrolment proportions in Year 12, and achievement levels in Year 12, across 2014, 2015, and 2016 were examined by calculating the average range of each of these measures in schools across these three years. Second, research suggests that achievement in senior STEM subjects is impacted upon by...
SES and location (ACARA, 2018; Connolly, 2017b; Thomson, De Bortoli, & Underwood, 2017; Thomson, Wernert, et al., 2017). Given this, construct validity of the school STEM success criteria was further explored by considering the correlation of achievement level with SES and location. Finally, SES has also been shown to impact on participation rates in senior STEM subjects. Students from lower SES backgrounds are more likely to enrol in practical STEM subjects, such as food technology or computing (Elsworth et al., 1999). Students from higher SES backgrounds are more likely to take high level mathematics subjects, chemistry, and physics (Fullarton et al., 2003; McPhan et al., 2008). Given this, construct validity was also tested by considering the patterns of individual subject participation in schools of different socio-economic status.

There is scant evidence in the literature about the impact of location on participation rates in senior STEM subjects, and only limited and inconclusive evidence that location impacts student STEM engagement (Hardré, 2011; Lyons & Quinn, 2010; Thomson et al. 2017a). Given this, exploring patterns of individual subject participation in schools of different location cannot contribute significantly to the content validity of the SSSC. However, this analysis was carried out in order to reveal new knowledge about the potential impact of location on senior STEM participation.

4.4.5 Identification of high STEM performing schools

For the purpose of identifying potential participant schools for Phase Two, schools were deemed to be high STEM performing if they performed better than the average for similar schools for each of the three school STEM success criteria described in Section 4.4. To determine this, schools were divided into one of eight like-school groups, first by categorising schools as metropolitan or non-metropolitan, then by dividing these groups into quartiles according to SES as explained in Section 4.4.3. The mean STEM enrolment proportions at Year 11 and Year 12, as well as the mean STEM achievement levels for each of these like-school groups were calculated. Each school’s score in each of these variables was then compared to the like-school group mean scores. A school was deemed to meet a criterion when the school’s score exceeded the like-school group mean. A school was deemed to be high STEM performing when it met all three criteria. Chapter 5 presents the findings of Phase One of this study.
4.5 Phase Two
Phase Two involved a multi-case study that included four of the high-STEM performing rural schools identified through Phase One in order to address the study’s second and third research questions:

1. What practices are believed to have contributed to the success of these high STEM performing rural schools?
2. To what extent do the practices of high STEM performing rural schools reflect factors proposed in the literature as contributing to school STEM success?

4.5.1 Case selection
DET re-identified the 25 high STEM performing non-metropolitan schools selected through Phase One to be considered as participants in Phase Two. Once identified it became apparent that six of these schools were located in regional cities, and were removed from the pool of potential participants as not being rural schools as defined in Section 1.7. A purposive sample (Cohen et al., 2011) of four rural schools was made from the remaining 19 schools. Purposive sampling includes various non-probability sampling strategies aimed at achieving particular goals (Teddlie & Yu, 2007). In this study, purposive sampling was used to allow the comparison of typical cases from the pool of rural schools identified as high STEM performing. The high STEM performing rural schools varied in school type, with eight being secondary schools, catering for Years 7-12, and eleven being P-12 colleges, with students from the first year of school through to Year 12. The schools also varied according to their socio-economic status. The four schools included in the purposive sample were selected as typical variants of the school type and SES levels of the 19 high STEM performing rural schools. The four schools selected, identified by their assigned pseudonyms, are shown in Table 5. It should be noted that school SES in Table 5 is indicated using the Index of Community Socio-Educational Advantage for the sake of transparency, as this index is used publicly. The SFOE data used in Phase One is used internally by the Victorian DET, however is not published publicly. Sweeping Plains College was selected as a P-12 school serving a relatively low SES rural community. River Valley College was selected as a P-12 school serving an average SES rural community. Alpine Secondary College was selected as a secondary school serving a slightly above average SES rural community. Coastal Secondary College was selected as a secondary school serving an average SES rural community.
Table 5

Schools selected to participate in Phase Two

<table>
<thead>
<tr>
<th>School pseudonym</th>
<th>School type</th>
<th>ICSEA* in 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweeping Plains College</td>
<td>P-12</td>
<td>963</td>
</tr>
<tr>
<td>River Valley College</td>
<td>P-12</td>
<td>992</td>
</tr>
<tr>
<td>Alpine Secondary College</td>
<td>Secondary</td>
<td>1023</td>
</tr>
<tr>
<td>Coastal Secondary College</td>
<td>Secondary</td>
<td>1002</td>
</tr>
</tbody>
</table>

*Index of Community Socio-Educational Advantage (ICSEA). ICSEA calculates a school’s level of educational advantage using parental education and occupation, as well as the school’s location and proportion of Indigenous students (ACARA, 2015). The national average ICSEA is 1000.

4.5.2 Data Collection

Site visits were conducted from May 2018 to August 2018. Visit times and structures were negotiated with the school principal. The ethical management of these arrangements is addressed in Section 4.6. The site visits for River Valley College and Coastal Secondary College spanned two school days, while the visits to Alpine Secondary College and Sweeping Plains College were completed in a single day. At each school, the principal, or a delegate, arranged the schedule of these days, including arranging access to participants, an appropriate space and times for interviews, and a tour of facilities. The principal or delegate also provided some of the documentary data requested electronically, either before or after the visit.

For each school, data were collected from various sources, providing multiple measures and perspectives on the STEM success of the school, and contributing to the rigor of the study (Tracy, 2010).

Quantitative data were obtained about each school from a variety of sources:

- Data about each school’s participation and achievement in senior STEM subjects across 2014, 2015 and 2016 through a request to the DET Victoria.
- Data about general senior school participation and success rates where extracted from the VCAA’s (VCAA) Senior Secondary Completion and Achievement Information (VCAA, 2018).
- Data about the National Assessment Program – Literacy and Numeracy (NAPLAN) reading and numeracy performance of the relevant cohort at each school was extracted from the MySchools website (ACARA, 2019). The relevant cohort refers to those students who completed Year 12 in years 2014, 2015 and 2016. This cohort
completed their Year 9 NAPLAN testing three years prior, and their Year 7 NAPLAN testing two years prior to that. Consequently, the relevant Year 9 NAPLAN data was collected from years 2011, 2012, 2013, and the relevant Year 7 NAPLAN data was collected from years 2009, 2010, 2011.

Qualitative data were gathered during site visits through semi-structured interviews with Year 12 students, STEM teachers, and school principals. A semi-structured format was selected to capitalise on the more equitable relationship established between interviewer and interviewee(s) through the less formal format, and to allow unanticipated topics to emerge during the interview (Gideon & Moskos, 2012). Further, a semi-structured interview provides the flexibility for interviewees to present ideas and insights they feel are pertinent, placing significant value on participant perspectives, as per Appreciative Inquiry (Reed, 2007). Some structuring of the interview was required to ensure the participants considered all potential contributors to their school’s relative STEM success, and this was achieved using open-ended questions (Gideon & Moskos, 2012). Information sheets and consent forms (see Appendices C & D) had been distributed to participants by the principal or delegate prior to the school visit. Interviews took place in private rooms or offices at the school. Participants met with the researcher at the interview location and submitted their signed consent form prior to the interview commencing. Participants were told the interviews were to be voice recorded, and the voice recorder was placed on a table between the researcher and interviewee(s). The use of voice recording is known to raise concerns for interviewees around confidentiality and data use (Gideon & Moskos, 2012). Consequently, it was made clear through the information sheet, at the start of each interview, and throughout the interviews where appropriate, that the interviewees’ responses would be kept confidential. Further, these mechanisms were also used to emphasise that interviewees could withdraw from the study at any time during the interview. Interviews varied in length from 20 – 40 minutes.

**Staff interviews**

Data pertaining to the staff interviews are shown in Table 6. Participation rates were calculated by dividing the number of STEM teacher interview participants by the total number of teachers at the school teaching at least one STEM subject at the school. Unfortunately, data about the total number of STEM teachers at Coastal Secondary College was not provided. As can be seen the majority of interview participants at all sites were mathematics and/or science teachers.
STEM teachers, leaders and principals were usually interviewed individually, however interviews were conducted in pairs (on two occasions) and in groups (on two occasions) as indicated in Table 6, if participants were only available at particular times. This risked potential issues of ‘group think’ or some views of members of the group not being presented (Cohen et al., 2011), particularly as one group interview included the principal. The anonymous teacher survey completed after these interviews, described below, provided an opportunity for participants to share views they may have felt unwilling to share in the group interview. These participants were asked which subjects they taught and what their role was at the school. They were not specifically asked about their qualifications or time working in schools, however they often revealed information about their experience, education, and tenure at the school as the interview progressed. The pseudonyms and roles of staff interviewees from each school are shown in Table 6. The questions guiding interviews with school staff are shown in Appendix E.1. As can be seen in Appendix E.1, these interviews commenced with a very broad question that adopted an appreciative orientation: “What do you feel are the largest contributors to student engagement in STEM at your school? What about the contributors to student achievement?” This allowed interviewees to raise topics that they felt were relevant, rather than being constrained by the nature of the question, allowing for the potential that themes would arise that had not occurred to the researcher as important (Gideon & Moskos, 2012), privileging participant insights as per Appreciative Inquiry (Reed, 2007). As the interview progressed, the questions became more structured. Participants were asked to describe how the elements contributing to STEM success were developed and maintained. They were also asked to describe the challenges to STEM education faced at the school and how they were overcome. Finally, interviewees were asked explicitly about the contribution of practices represented in the STEM education literature to the success of STEM education at the school through a question with the stem: “What (if any) impact have the following had on your school’s success in STEM education?”
Table 6

Staff interview participants and roles by school

<table>
<thead>
<tr>
<th>School</th>
<th>STEM teacher participation rate</th>
<th>Staff member pseudonym and gender</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweeping Plains College</td>
<td>6/13 (46%)</td>
<td>Kevin (male)</td>
<td>Principal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Karen* (female)</td>
<td>Numeracy leader, Teacher (Mathematics)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Craig* (male)</td>
<td>Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leanne (female)</td>
<td>Teacher (Science)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paul (male)</td>
<td>Technology leader, Teacher (Technology)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gerty (female)</td>
<td>Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adrian (male)</td>
<td>Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td></td>
<td>**</td>
<td>Janet (female)</td>
<td>Principal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liz** (female)</td>
<td>Numeracy leader, Teacher (Mathematics)</td>
</tr>
<tr>
<td></td>
<td>8/13 (62%)</td>
<td>Veronica** (female)</td>
<td>Mathematics leader, Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stuart (male)</td>
<td>Science leader, Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STEM teachers (Meredith, Joan, Simon, Narelle, Douglas, Stuart, Liz, Veronica, Janet)</td>
<td>8 teachers of Mathematics, Science &amp; Technology and the Principal</td>
</tr>
<tr>
<td>Alpine Secondary College</td>
<td>7/12 (58%)</td>
<td>Sally (female)</td>
<td>Principal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jirra (female)</td>
<td>Mathematics &amp; Science leader, Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Craig (male)</td>
<td>Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tracy (female)</td>
<td>Laboratory manager</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STEM teachers (Peter, Nancy, Britta, Yvonne, Jirra)</td>
<td>5 teachers of Mathematics, Science &amp; Technology</td>
</tr>
<tr>
<td></td>
<td>Total number of STEM teachers unknown</td>
<td>Matt (male)</td>
<td>Principal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dave (male)</td>
<td>Assistant Principal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Janak (male)</td>
<td>Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wil (male)</td>
<td>Mathematics leader, Teacher (Mathematics)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jill (female)</td>
<td>Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Terry (male)</td>
<td>Science leader, Teacher (Mathematics, Science)</td>
</tr>
</tbody>
</table>

* Kim and Craig were interviewed as a pair at Sweeping Plains College.

** Liz and Veronica were interviewed as a pair at River Valley College.
Student group interviews

Year 12 STEM students from each school were interviewed in one or two groups of five to eight students with only the researcher present. The numbers and genders of students participating in these interviews are shown in Table 7. The group interview format was selected as a less intimidating mode of interview (Cohen et al., 2011). By completing the interview with peers it was hoped students would feel more comfortable to participate than they might in a one-on-one interview with a researcher they had not previously met. The short comings associated with group interviews of one respondent dominating the interview or issues of ‘group think’ (Cohen et al., 2011) were managed by the interviewer using his skills as an experienced teacher, individually inviting each participant to respond and checking for differences of opinion. The questions asked of student groups are shown in Appendix E.2. As with the staff questions, student questions had an appreciative orientation. All questions were broad, avoiding potentially constraining student responses and allowing themes to arise that the researcher may not have anticipated (Gideon & Moskos, 2012). The opening question was: “What are some of the best learning experiences you had studying science, maths, or technology before you began VCE? Why were these some of the best learning experiences in these subjects?” Students were then asked to describe how teachers of STEM at their school teach, how students of STEM at their school learn, and how students are encouraged to be interested in STEM at their school. They were also asked to give their opinion as to why they think their school is doing better in STEM education than similar schools.

Table 7

Student numbers and gender distribution by school in student group interviews

<table>
<thead>
<tr>
<th>School</th>
<th>Female</th>
<th>Male</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweeping Plains College</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>River Valley College</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Alpine Secondary College</td>
<td>6</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Coastal Secondary College</td>
<td>7</td>
<td>2</td>
<td>9</td>
</tr>
</tbody>
</table>
Other data collected during school visits

During the visit to each school, the researcher toured the school accompanied by the school principal or a delegate. This provided an opportunity to photograph and take field notes about the facilities, displays, and other educational artefacts around the school. The researcher also collected documents including a current strategic plan with school profile, and all subject selection booklets made available to students and parents. Where possible, these documents were supplemented with planning documents for STEM subjects, school timetables, and other documentation the participating staff felt relevant to the study.

Teacher survey

Additional qualitative data were collected from staff at all four schools using an online survey delivered through surveymonkey (see Appendix F). Volunteer sampling (Hibberts et al., 2012) was used, with all STEM teachers being invited to participate after the researcher had visited the school via an email with a link to the survey forwarded by the principal. STEM teachers included any teachers of Science, Mathematics, Engineering, Technology, or subjects incorporating one or more of these disciplines. The invitation to participate in the survey was extended after the school visits in the hope that it may increase participation as participants would be more likely to see the researcher as a credible and legitimate authority (Stalans, 2012) having met him. Table 8 shows the number of respondents to the online survey from each school.

Table 8

Number of respondents to online STEM teacher survey from each school

<table>
<thead>
<tr>
<th>School</th>
<th>Number of survey respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweeping Plains College</td>
<td>5</td>
</tr>
<tr>
<td>River Valley College</td>
<td>7</td>
</tr>
<tr>
<td>Alpine Secondary College</td>
<td>7</td>
</tr>
<tr>
<td>Coastal Secondary College</td>
<td>3</td>
</tr>
</tbody>
</table>

As can been seen in Appendix F, an appreciative frame was also adopted in the survey introduction and open response questions (Stalans, 2012), where it was explained that staff were being invited to complete the survey as their school had been identified as a high STEM performing school. This appreciative frame, along with the anonymous nature of the survey, was designed to elicit honest and open responses from participants. Gideon’s (2012)
guidelines for questionnaire design were employed, including piloting the survey with four experienced educators. While the survey posed a series of closed questions this data are not analysed or presented in this thesis. Only the six open-ended questions (Cohen et al., 2011) were used in this thesis as an anonymous source of STEM teacher beliefs about what has contributed to their school’s success in STEM education. The construct definition (Gideon, 2012) of success in STEM education was made clear in both the survey introduction and the introduction to the open questions as being high participation and achievement in STEM education relative to similar schools.

4.5.3 Case analysis
An explanation building approach to analysis, where a set of causal links are sought to explain how and why a phenomenon occurred, was employed for these case analyses (Yin, 2014). In this study the phenomenon of interest is the high STEM performance of each of the schools. In line with the Appreciative Inquiry notion that ‘something works’ (Reed, 2007), it was assumed that the practices of the STEM educators at each school contributed to this success, that the resources, culture, and relationships at each school facilitated these practices. This is not to suggest that it was assumed that all STEM educators at the school were employing, or even effectively executing, the practices that contributed to school success. There is significant variance in the approach and effectiveness of teachers within any school (Hattie, 2009). Rather, it was assumed that combined, the practices of the STEM educators, and the practice architectures that enabled them at each school, had contributed substantially to the high senior STEM enrolment and achievement levels at each school. Given this, the conceptual framework outlined in Chapter 3 was used as the initial lens for analysis.

Open ended questions from the survey as well as transcripts of interviews with Principals, STEM teachers, and students, school documents and field notes made up the qualitative data corpus for each case. This body of evidence was analysed using thematic analysis. Thematic Analysis is a flexible method, capable of exploring the independent reality of participants, as well as the ways that reality is shaped by social constructs (Braun & Clarke, 2006). As such it is compatible with the conceptual framework that guided this study. Data were coded using both deductive and inductive themes (Braun & Clarke, 2006). Prior to collecting data, deductive themes were drawn from the theory of Practice Architectures elements of the conceptual framework of the project, as shown in Table 9. Initial analysis involved coding into these themes. Data that was evidence of elements of practices at the schools, either doings (distinctive actions), sayings (characteristic discourses), or relatings
(interactions between enactors of a practice or with the wider world) (Kemmis et al., 2014; Rönnerman & Kemmis, 2016), were coded into the practice theme. This included descriptions of typical or particular lessons, events, interactions, or incidents related to STEM education at the schools. Data that was evidence of factors enabling these practices, including material-economic arrangements, cultural-discursive arrangements, and social-political arrangements (Kemmis et al., 2014), were coded into the practice architectures theme. This included data associated with resourcing, staffing, communications, school culture, networks, and relationships impacting STEM education at the schools.

Table 9

Deductive themes for initial thematic analysis.

<table>
<thead>
<tr>
<th>Parent theme</th>
<th>Sub theme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice</td>
<td>Saying</td>
</tr>
<tr>
<td></td>
<td>Doing</td>
</tr>
<tr>
<td></td>
<td>Relating</td>
</tr>
<tr>
<td>Practice architecture</td>
<td>Cultural-discursive</td>
</tr>
<tr>
<td></td>
<td>Material-economic</td>
</tr>
<tr>
<td></td>
<td>Socio-political</td>
</tr>
</tbody>
</table>

Through iterative engagement with the data, inductive themes were identified in the light of the research questions, a process Braun and Clarke describe as “organic thematic analysis” (Braun & Clarke, 2016, p. 741). Transcribed interviews, the open ended responses to the teacher survey, school documents, and field notes and photographs were all analysed in this way.

The data source was also considered as part of the analysis. Triangulation of evidence from the voices of students, teachers, STEM leaders, and principals was important to the validity of the findings. Triangulation is where two or more data sources converge on a similar conclusion, allowing that conclusion to be viewed as more credible (Tracy, 2010). Triangulation through the lens of appreciative inquiry requires that the perspectives of participants from across an organisation be accounted for (Bergmark & Kostenius, 2018). Thus, in this study, a finding was adequately triangulated where the views of students, teachers, and school leaders converged. Viewed through the lens of the conceptual framework, the documents collected were considered part of the ‘sayings’ of each school,
tangible evidence of the cultural-discursive elements of a school’s practice architectures. However, they also documented evidence of the ‘doings’ and ‘relatings’ of each school. Evidence of artefacts, such as resources and facilities, collected through field notes and photographs also provided evidence of practices and practice architectures. Artefacts are outward ‘manifestations of organisational culture’ (Cohen et al., 2011, p. 532). Though visible, artefacts are difficult to interpret and are limited to indicating practices that may be occurring, but not the reasons why. The purpose, condition, location, and even production of artefacts flagged aspects of the cultural-discursive, material-economic, and/or socio-political elements of each school’s practice architectures that have impacted upon its STEM success.

The findings associated with each inductive theme were organised and discussed under the parent themes of practices contributing to school STEM success, and practice architectures enabling practices contributing to school STEM success, to produce a case study report for each school. Each school’s case study report was returned to the school for member checking (Hamilton & Corbett-Whittier, 2013). Common themes across the four schools were drawn together to produce a multi-case synthesis of practices believed to have contributed to rural school STEM success, and the practice architectures that enabled these practices. These findings are presented in Chapter 6 of this thesis.

4.5.4 Validity and credibility

Peer review, data triangulation, thick description, and member checking, were all used to ensure the validity and credibility of Phase Two of this study. Validity is viewed as how accurately accounts and inferences drawn from data reflect the realities of the participants in a study (Creswell & Miller, 2000). Credibility is a closely related concept, referring to how trustworthy and persuasive an account is (Tracy, 2010). In this study, the resulting case studies have validity to the extent that they reflect the realities of students and staff at the schools investigated, and credibility to the degree that a reader finds them a plausible and trustworthy information source upon which to act. Similar strategies can be used to build both validity and credibility. Peer review involves review of methodology and findings by someone familiar with both the research approach and context (Creswell & Miller, 2000). Peer review was used to contribute to establishing validity in this study in two ways. First, the two academics supervising me as I carried out this study, both experienced in case study methods in educational contexts, reviewed the planned methodology to ensure the methods chosen would effectively collect a breadth and depth of data to support making valid
findings. Second, the case studies produced through these methods were reviewed by the same researchers to check their credibility.

Data triangulation involves seeking corroboration of phenomenon from multiple data sources (Yin, 2014), contributing to validity and credibility. In this study, data triangulation was planned for by seeking evidence pertaining to each school’s STEM success from interviews with students, STEM teachers and principals, as well as documents, artefacts, and teacher surveys. Triangulation was used in the analysis with emergent themes identified when supported by evidence from multiple sources. Such an approach is widely believed to produce higher quality, more credible case studies (Yin, 2014). The use of multiple sources of information also supported the use of thick description in the case studies. Thick descriptions improve credibility through the use of extensive illustration and detail to reveal the complexity of the data informing findings (Tracy, 2010). In documenting this study, each of the themes presented are supported by illustrations from across the data sources.

Finally, member checking was used to have some of the study’s participants assess the validity of the findings. Member checking involves participants reviewing the account their data has contributed to (Hamilton & Corbett-Whittier, 2013). Case study reports were returned to school principals to check for misrepresentations or errors. Each principal was given more than a month to complete this task. In each case, principals expressed no concerns about, or suggested any amendments to, the reports distributed.

4.6 Ethical considerations
There are a range of ethical considerations associated with this study. Some of these are related to the use of sensitive school-level data during Phase One, and some with the recruiting process, and the use of interviews and group interviews in Phase Two.

4.6.1 Phase One ethics
Phase One required the use of school level data about the average enrolment rates and achievement levels in VCE STEM subjects, that, if misused, could cause reputational harm. While the VCAA (VCAA) annually publishes the median study score achieved by each Victorian school delivering the VCE (VCAA, 2019b), it does not publicly release data about school performance by subject. Such data has the potential to cause harm to schools, teachers, and potentially even students. A low result in any one year in a particular subject for a school may damage the public perception of that school’s ability to effectively deliver that subject. Further, as subjects, particularly some STEM subjects, are delivered by one teacher, or only
small groups of teachers, at a school, the release of such data could damage the reputation of, or embarrass, particular teachers. Finally, given some STEM classes attract relatively low enrolments, particularly physics, chemistry, and advances mathematics, the publication of these results could result in the humiliation of individual or groups of students in these classes.

Given the sensitivity of the data required for Phase One, the researcher negotiated a form of data, and process of release, that would protect schools, teachers and students from harm. After discussions with the manager of Strategic Research of the Performance and Evaluation Division (PED) of the Victorian DET, a decision was made to apply to access de-identified data for every Victorian government secondary school to complete Phase One of the project, in order to select relatively high STEM performing schools. An agreement was made that once selected, these high STEM performing schools would be re-identified, the rationale being that the STEM achievement and enrolment data associated with these successful schools would have minimal risk of causing harm to individual schools, teachers, or students. On this basis an application to conduct Research in Victorian Government Schools and/or Early Childhood Settings (RISEC) was made and approved (see Appendix G), and the data were released for analysis in Phase One. Concurrently, a successful application was made for Human Research Ethics Approval (protocol number 100/2017/23), to the Charles Sturt University Human Research Ethics Committee (see Appendix H).

4.6.2 Phase Two ethics
Phase Two involved investigation of four high STEM performing rural schools. The conceptual framework guiding this study, informed by Appreciative Inquiry (see Section 3.2), guides an approach where participants reflect upon what has contributed to their school’s relative STEM success, and thus provided a degree of protection from participants exploring sensitive or distressing topics. However, it does not preclude harm being caused by the process or the content of the Phase Two inquiry. Foreseeable potential harms to participants in Phase Two included: inconvenience associated with the time lost to participating in interviews; anxiety associated with perceived pressure to participate; concerns that their responses may be judged negatively; and concerns about maintaining anonymity and confidentiality. A range of mechanisms were employed to further mitigate any harms.

The principal was involved in determining the scheduling and form of each school visit, so that their knowledge of local context and demands could help reduce potential harm and inconvenience for participants. Schools were initially approached to be involved in the
study via a letter to the principal (see Appendix I). If the principal indicated a willingness for their school to be involved in the study, I negotiated with them a site visit day(s) that would cause least inconvenience to the STEM staff and the Year 12 students who may consent to be involved. The principal or a delegate took responsibility for recruiting staff and student participants using the information sheets and consent forms provided (see Appendices C & D). The principal or a delegate also scheduled interview times that best suited the consenting participants. Having the principal, or principal delegate, involved in recruiting introduces the potential that some participants may have felt coerced to participate, given the principal’s position in the school hierarchy. In an attempt to mitigate against this I confirmed consent with each participant verbally (see Appendix E), before commencing any interviews. As stated in all participant information sheets, the confidentiality of participants’ interview responses was actively protected, with data being securely stored, viewable only by the researcher, and pseudonyms being applied to data for reporting purposes (see Appendix C). These measures mitigated against any ethical concerns associated with school principals being involved in the recruitment process. No participant at any of the schools chose to withdraw.

The potential that participants may feel as though their responses were being judged was managed by emphasising the appreciative lens of the study. Participants were repeatedly reminded that the study was investigating how their school had achieved success in STEM, and the study aimed to learn from their experiences. Interview questions were fashioned to emphasise this appreciative aspect, with questions like ‘Why do you think your school is doing better in STEM education than other similar schools?’ for students, or ‘How do you think the elements contributing to your school’s success in STEM were developed? How are these elements maintained?’ for STEM teachers (see Appendix E).

A range of mechanisms were employed to manage concerns about maintaining anonymity and confidentiality. Interviews were held in private rooms with only myself and participants present. Information sheets, and interview scripts all emphasised that participants would not be identified in any publications or reporting of the findings of the project. Interviews were transcribed using pseudonyms. The combination of school and participant pseudonyms is a strong safeguard of participant identities. Group interviews pose a particular challenge to anonymity and confidentiality. While the researcher offered documented commitments to protect participant identity, there was no guarantee that other participants in the group would. To manage this participants in group interviews were reminded at the commencement and conclusion of the interviews, ‘Please remember that what is discussed
today is to remain confidential.’ (see Appendix E.2). During school tours, where photos were taken of artefacts, care was taken that no individual would be identifiable in the image. Finally, data has been kept electronically in password protected files and has only been viewed by the researcher and his supervisors. No hardcopies were made of the data.

Group interviews pose two further ethical challenges. First, participants may feel more anxious to withdraw from the study in front of others. Second, domineering personalities, or potential judgement by other participants, may make some participants less comfortable or less likely to make contributions (Iphofen & Tolich, 2018). These potential effects were managed by drawing on my experience as a teacher and educational leader well accustomed to managing group discussions of students and teachers, often in difficult circumstances or on sensitive topics.

4.7 Summary

This chapter described the methodology of the two phases of this study conducted in Victoria, Australia. Phase One involved establishing the validity of the school STEM success criteria, then applying the criteria to identify relatively high STEM performing rural Victorian schools. First, the method used to establish both the content and construct validity of the school STEM success criteria was detailed. Content validity was established by demonstrating the theoretical link between student participation and achievement in senior STEM subjects, and their engagement and capability in STEM education more generally. Establishing construct validity involved exploring the manner in which the school STEM success criteria conforms to theoretical predictions, in particular, predictions about the impact of SES and location on both enrolments and achievement levels. Having described the methods used to validate the school STEM success criteria, the chapter explains how these criteria were applied to identify relatively high STEM performing rural Victorian government schools as potential sites for case study in Phase Two.

Phase Two involved the case study of four high STEM performing rural schools identified through Phase One. This chapter described the purposive sampling used for site selection, and the multiple-source data collection and explanation-building analysis approach used to develop the validity and credibility of each of the four case studies and the eventual multiple-case synthesis.

The chapter concludes by exploring the ethical considerations involved in this study, particularly those that relate to the use of sensitive school-level data during Phase One, and
those associated with the recruiting process, and the use of interviews and group interviews in Phase Two.
Chapter 5: Identifying high STEM performing rural Victorian government secondary schools

This chapter includes a number of excerpts from my published work. Specifically, excerpts have been taken from:


These publications are part of my PhD work. Each excerpt is clearly identified with a brief introduction, a reduced font size, and narrowed margins.

5.1 Preamble

This chapter presents the findings of Phase One, addressing the first research question, “Which rural Victorian government schools achieve relative success in STEM education?”

The schools of interest were Victorian government schools delivering the Victorian Certificate of Education (VCE). First, this chapter establishes the construct validity of the school STEM success criteria used to determine the relative STEM success of each school:

1. Mean school enrolment proportions in STEM subjects at Year 11 level across 2014, 2015, and 2016;

2. Mean school enrolment proportions in STEM subjects at Year 12 level across 2014, 2015, and 2016; and

In this chapter, the first two criteria are referred to as the STEM enrolment criteria, and the third criterion as the STEM achievement criterion.

Construct validity refers to the degree to which a measure aligns with the theoretical understanding of what is being measured (Cohen et al., 2011). The construct validity of the school STEM success criteria was established by demonstrating that each criterion (each a composite variable), and the variables composing that criterion, varied between schools, within schools, and between STEM subjects, in ways that would be predicted by theory. That is, evidence was sought that variations in socioeconomic status (SES) and school location were associated with variations in school STEM achievement levels and enrolment proportions as would be anticipated on the basis of previously published research.

After establishing the construct validity of the school STEM success criteria, the chapter presents the mean performance of metropolitan and non-metropolitan schools in each SES quartile against each criterion, thus identifying the threshold for each like-school group. Schools were deemed to have met the threshold for relative success against any one of these criteria when their mean was higher than the average score of the like-school group – those in a similar location (metropolitan or non-metropolitan) and in the same socio-economic status (SES) quartile. A school was considered high STEM performing only when they met this threshold for all three criteria. The chapter presents the proportion of schools in each like-school group that met these criteria, including the proportion of schools that meet all three criteria. The chapter concludes identifying the number of rural schools that met all three criteria and were thus viewed as relatively high STEM performing and potential participants in Phase Two of this study.

5.2 Establishing the construct validity of the School STEM Success Criteria

Construct validity refers to the degree to which a measure aligns with the theoretical understanding of what is being measured (Cohen et al., 2011). The construct validity of the School STEM Success Criteria was established by showing that the criteria (each a composite variable), and variables composing the criteria, varied between schools, within schools, and between STEM subjects, in ways that would be predicted by theory. That is, evidence was sought that variations in socioeconomic status (SES) and school location were associated with variations in school STEM achievement levels and enrolment proportions as would be anticipated on the basis of previously published research. Much of the research informing current theory has been focused on engagement and achievement in the separate STEM disciplines of mathematics, science, and technologies, rather than STEM as a whole. Given
this, the way SES and location vary with the variables that make up each criterion, as well as the criterion as a whole, is considered in this section. For example, not only is the relationship of SES and location with mean STEM achievement levels examined, but also their relationship with achievement levels in mathematics, science and technology. In doing so, excerpts and tables from three papers already published from the work comprising this thesis are presented in this chapter.

5.2.1 Testing the stability of the School STEM Success Criteria within schools

It is well established that school factors influence student engagement and achievement in STEM (Drent et al., 2013; Grootenboer & Hemmings, 2007; Holmes et al., 2018; Palmer et al., 2017). Given this, it would be expected that average senior STEM enrolment proportions and average STEM achievement levels would vary between schools, while remaining relatively stable within schools from year to year. If, on the other hand, engagement and achievement is mostly due to student factors, average senior STEM enrolment proportions and average STEM achievement levels would vary both between and within schools from year to year with the change of student cohort.

Table 10 shows the mean enrolment proportions and achievement level of all Victorian government schools from 2014 to 2016, as well as the minimums and maximums for these variables. This shows there are large differences in STEM enrolments and achievement levels between schools.

Table 10

*Means of all Victorian government schools from 2014 to 2016 for Year 11 STEM enrolment proportions, Year 12 STEM enrolment proportions, and Year 12 STEM achievement levels.*

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean of all schools (Min. - Max.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 STEM enrolment proportion</td>
<td>0.41 (0.14 – 0.63)</td>
</tr>
<tr>
<td>Year 12 STEM enrolment proportion</td>
<td>0.41 (0.13 – 0.66)</td>
</tr>
<tr>
<td>Year 12 STEM Achievement level</td>
<td>27.28 (16.02 – 37.44)</td>
</tr>
</tbody>
</table>

Table 11 shows the mean range of all schools for enrolment proportions and achievement level variables, that is, the average amount these variables changed across 2014, 2015, and 2016, as well as the minimum and maximum change any single school experienced.
for each of these variables. It shows that while these variables varied greatly within some schools across 2014, 2015 and 2016, the average range was quite small, particularly compared to the mean score for these variables shown in Table 10. For example, some schools’ STEM achievement levels varied as little as 0.10 points in the years 2104-2016, where others varied by up to 12.48 points. However, the mean variation was only 2.43 points, or less than 9% of the mean school achievement level of 27.28. Similarly, while some school’s showed large variability in STEM enrolment proportions across the three years, the mean 2014-2016 range of all schools for Year 11 and 12 STEM enrolment proportions was also relatively small. These findings suggest that enrolment proportions and achievement levels are relatively stable within each school. This aligns with previous research suggesting that school factors have a bearing on student engagement and achievement in STEM, thus contributing to the construct validity of the school STEM success criteria, and the validity of applying these criteria for determining relative school STEM success.

Table 11

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean range of all schools (Min. range - Max. range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 STEM enrolment proportion</td>
<td>0.07 (0.00 – 0.53)</td>
</tr>
<tr>
<td>Year 12 STEM enrolment proportion</td>
<td>0.08 (0.00 – 0.64)</td>
</tr>
<tr>
<td>Year 12 STEM Achievement level</td>
<td>2.43 (0.10 – 12.48)</td>
</tr>
</tbody>
</table>

5.2.2 Examining the relationship of SES to the subject enrolment proportion criteria

SES has been shown to impact on participation rates in senior STEM subjects. As discussed in Section 2.6 of this thesis, students from lower SES backgrounds are more likely to enrol in practical STEM subjects, such as food technology or computing (Elsworth et al., 1999). Students from higher SES backgrounds are more likely to take high level mathematics subjects, chemistry, and physics (Fullarton et al., 2003; McPhan et al., 2008).
The relationship of SES to mathematics enrolment proportions

Research shows that SES impacts both student engagement in mathematics and their selection of senior mathematics courses. In my paper included in Appendix J I provided this brief summary:

As parental education and occupation levels increase, so does the number of students enrolling in advanced mathematics courses (McPhan et al. 2008). Studies shed some light on why SES may have this impact by considering engagement with mathematics in the early years of secondary schooling. TIMSS attitudinal surveying shows that by year 8, lower SES students report not liking learning mathematics in significantly higher proportions than other students. PISA measurements of student motivation to learn and succeed in mathematics suggest that year 9 students from high SES backgrounds were far more motivated to achieve in mathematics than other students. Martin et al. (2015) suggest that students from lower SES schools are more likely to self-handicap, become disengaged and to have reduced class participation in mathematics.

(Murphy, 2019b, p. 222, see Appendix J)

This study showed that this relationship between SES and enrolments was reflected in the findings associated with the mathematics component of the School STEM Enrolment Criteria. In the excerpt of my paper below, the relationship between SES and enrolments in this study was explored through simple description of the data as well as through the calculation of a Spearman’s rho correlation coefficient. A Spearman correlation measures the strength of the association between two ordinal variables (Frey, 2018). The Spearman’s rho correlation coefficient indicates both how closely two variables are related as well as the direction of the relationship. The closer the magnitude of the Spearman’s rho correlation coefficient is to 1.0, the stronger the relationship between the variables – that is, the more likely it is that as one variable changes, the other variable changes a similar amount. The direction of the relationship is indicated by the sign of the coefficient – a positive Spearman’s rho correlation coefficient indicates that as one variable increases the other does also, where as a negative Spearman’s rho correlation coefficient indicates as one variable increases, the other decreases. In this study, enrolment proportions in advanced mathematics subjects were positively correlated with SES, while enrolment proportions in entry level mathematics were negatively correlated with SES. In my paper included in Appendix J I explained:
Table [12] shows that the enrolment proportion for each of the VCE mathematics subjects varies with SES. The proportion of enrolments for Year 11 General Mathematics and Year 12 Foundation Mathematics are slightly lower in the highest SES schools… compared to all other schools. However, the enrolment proportion for Year 11 Foundation Mathematics in the lowest SES schools is nearly twice that of the enrolment proportion in the highest SES schools. This trend is reversed for the uptake of Mathematical Methods and Specialist Mathematics. The highest SES schools have greater enrolment proportions in both [advanced] mathematics studies at Year 11 and Year 12 levels, compared to the lower SES schools.

The relationship between [SES] and enrolment proportions was investigated by calculating Spearman’s rho correlation coefficients for each subject, across all schools… As can be seen in Table [13], there is a weak [negative] correlation between [SES] and enrolment proportions in Year 11 Foundation Mathematics (ρ = 0.24), and a moderate [negative] correlation in Year 12 Further Mathematics (ρ = 0.34). However, there is a moderate [positive] correlation between [SES] and enrolment proportions across all schools in Year 11 Mathematical Methods (ρ = -0.47), a weaker moderate [positive] correlation in Year 11 Specialist Mathematics (ρ = -0.38) and Year 12 Mathematical Methods (ρ = -0.36), and a weak [positive] correlation in Year 12 Specialist Mathematics (ρ = -0.29).

(Murphy, 2019b, p. 227-228, see Appendix J)

Collectively, these findings show that as SES increases, so do the enrolment proportions in the advanced mathematics subjects (i.e., Mathematical Methods and Specialist Mathematics). Conversely, as SES increases, the enrolment proportions in the most accessible mathematics subjects (i.e., Foundation Mathematics, General Mathematics, and Further Mathematics) decrease. These findings are in line with previous research findings, contributing to the construct validity of the school STEM enrolment criteria.

The relationship of SES to science enrolment proportions

Similar to in mathematics, research shows that SES impacts student engagement in science. In my paper included in Appendix K, I gave this overview:

In Australia, Cooper et al. (2018) found that the higher the SES of students 16 years or older, the more likely they would be enrolled in a science subject. An earlier study suggested that high SES students were more likely than others to enrol in Chemistry or Physics (Fullarton et al. 2003). Students from higher SES backgrounds report having higher levels of interest in science and enjoyment in learning science (Thomson et al. 2017a). Lower SES students were less likely to see
career and job opportunities as a motivating factor in their science studies (Thomson et al. 2017a). This reflects an international trend where disadvantaged students are less likely to aspire to a career in science, even when accounting for science achievement (OECD 2018).

(Murphy, 2018a, p. 6, see Appendix K)

**Table 12**

*Enrolments in VCE mathematics subjects as a proportion of all VCE subject enrolments by SES quartile.*

<table>
<thead>
<tr>
<th></th>
<th>SES Quartile 1 (lowest SES)</th>
<th>SES Quartile 2</th>
<th>SES Quartile 3</th>
<th>SES Quartile 4 (highest SES)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (Range)</td>
<td>Mean (Range)</td>
<td>Mean (Range)</td>
<td>Mean (Range)</td>
</tr>
<tr>
<td>Year 11 Foundation Mathematics</td>
<td>0.035 (0-0.086)</td>
<td>0.029 (0.001-0.112)</td>
<td>0.028 (0-0.058)</td>
<td>0.018 (0-0.062)</td>
</tr>
<tr>
<td>Year 11 General Mathematics</td>
<td>0.109 (0.020-0.196)</td>
<td>0.114 (0.051-0.171)</td>
<td>0.108 (0.005-0.180)</td>
<td>0.095 (0.047-0.158)</td>
</tr>
<tr>
<td>Year 12 Further Mathematics</td>
<td>0.125 (0.039-0.181)</td>
<td>0.133 (0.086-0.191)</td>
<td>0.127 (0.008-0.200)</td>
<td>0.103 (0.026-0.169)</td>
</tr>
<tr>
<td>Year 11 Mathematical Methods</td>
<td>0.041 (0.004-0.092)</td>
<td>0.042 (0.017-0.096)</td>
<td>0.049 (0.007-0.090)</td>
<td>0.074 (0.012-0.172)</td>
</tr>
<tr>
<td>Year 12 Mathematical Methods</td>
<td>0.039 (0.006-0.094)</td>
<td>0.037 (0.004-0.103)</td>
<td>0.040 (0.004-0.098)</td>
<td>0.064 (0.012-0.155)</td>
</tr>
<tr>
<td>Year 11 Specialist Mathematics</td>
<td>0.005 (0.001-0.017)</td>
<td>0.006 (0-0.026)</td>
<td>0.005 (0.001-0.013)</td>
<td>0.010 (0.001-0.037)</td>
</tr>
<tr>
<td>Year 12 Specialist Mathematics</td>
<td>0.014 (0.002-0.055)</td>
<td>0.009 (0.001-0.024)</td>
<td>0.011 (0.002-0.030)</td>
<td>0.022 (0.001-0.075)</td>
</tr>
</tbody>
</table>

### Table 13

**Spearman’s rho correlation coefficients for SES and VCE mathematics subject enrolment proportions**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Correlation with SES $r_s$ (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 Foundation Mathematics enrolments</td>
<td>-0.24 (204)</td>
</tr>
<tr>
<td>Year 11 General Mathematics enrolments</td>
<td>-0.19 (286)</td>
</tr>
<tr>
<td>Year 12 Further Mathematics enrolments</td>
<td>-0.34 (284)</td>
</tr>
<tr>
<td>Year 11 Mathematical Methods enrolments</td>
<td>0.47 (285)</td>
</tr>
<tr>
<td>Year 12 Mathematical Methods enrolments</td>
<td>0.36 (280)</td>
</tr>
<tr>
<td>Year 11 Specialist Mathematics enrolments</td>
<td>0.38 (145)</td>
</tr>
<tr>
<td>Year 12 Specialist Mathematics enrolments</td>
<td>0.29 (227)</td>
</tr>
</tbody>
</table>


This relationship between SES and student engagement is reflected in this study’s Phase One findings associated with the science component of the school STEM enrolment criteria. In my paper included in Appendix K, I explained:

Table [14] lists the mean enrolment proportions and the range of enrolment proportions for each of the VCE studies by [SES] quartile. It illustrates some differences in the enrolment proportions of some subjects in schools of different SES. Chemistry and Physics both attract a greater share of enrolments in the highest SES schools than schools at other SES levels. In contrast, Year 12 Psychology attracts greater enrolment proportions in the lowest SES schools than any other SES level.

Spearman’s rho correlation coefficients were calculated to explore the relationship between [SES] and enrolment proportions further. Table [15] lists the correlation coefficients for each subject, across all schools... The data in Table 5 shows that there is no linear relationship between [SES] and the enrolment proportions of Year 11 Biology, Year 12 Biology, or Year 11 Psychology, and small to small-medium [positive] correlations in all the other sciences.

(Murphy, 2018a, p. 10, see Appendix K)

Collectively, these findings show that as SES increases, so do the enrolment proportions in Chemistry and Physics, science subjects that serve as prerequisites for
entry into many tertiary STEM courses (VTAC, 2016). These findings are in line with previous research findings, contributing to the construct validity of the school STEM enrolment criteria.

Table 14

*Enrolments in VCE science subjects as a proportion of all VCE subject enrolments by SES quartile.*

<table>
<thead>
<tr>
<th></th>
<th>SES Quartile 1 (lowest SES)</th>
<th>SES Quartile 2</th>
<th>SES Quartile 3</th>
<th>SES Quartile 4 (highest SES)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (Range)</td>
<td>Mean (Range)</td>
<td>Mean (Range)</td>
<td>Mean (Range)</td>
</tr>
<tr>
<td>Year 11 Biology</td>
<td>0.048 (0.004-0.089)</td>
<td>0.048 (0.003-0.084)</td>
<td>0.054 (0.007-0.136)</td>
<td>0.049 (0.019-0.080)</td>
</tr>
<tr>
<td>Year 12 Biology</td>
<td>0.049 (0.017-0.082)</td>
<td>0.052 (0.022-0.130)</td>
<td>0.057 (0.027-0.163)</td>
<td>0.050 (0.015-0.103)</td>
</tr>
<tr>
<td>Year 11 Chemistry</td>
<td>0.031 (0.002-0.074)</td>
<td>0.031 (0.002-0.065)</td>
<td>0.034 (0.013-0.084)</td>
<td>0.048 (0.011-0.167)</td>
</tr>
<tr>
<td>Year 12 Chemistry</td>
<td>0.027 (0.004-0.061)</td>
<td>0.026 (0.005-0.053)</td>
<td>0.029 (0.011-0.098)</td>
<td>0.040 (0.008-0.161)</td>
</tr>
<tr>
<td>Year 11 Environmental Science</td>
<td>0.006 (0.001-0.011)</td>
<td>0.005 (0.000-0.012)</td>
<td>0.014 (0.002-0.050)</td>
<td>0.006 (0.003-0.011)</td>
</tr>
<tr>
<td>Year 12 Environmental Science</td>
<td>0.013 (0.008-0.022)</td>
<td>0.005 (0.004-0.121)</td>
<td>0.021 (0.008-0.098)</td>
<td>0.010 (0.002-0.020)</td>
</tr>
<tr>
<td>Year 11 Physics</td>
<td>0.022 (0.001-0.059)</td>
<td>0.025 (0.002-0.073)</td>
<td>0.026 (0.006-0.063)</td>
<td>0.034 (0.008-0.074)</td>
</tr>
<tr>
<td>Year 12 Physics</td>
<td>0.022 (0.003-0.049)</td>
<td>0.025 (0.005-0.083)</td>
<td>0.024 (0.005-0.059)</td>
<td>0.032 (0.006-0.078)</td>
</tr>
<tr>
<td>Year 11 Psychology</td>
<td>0.059 (0.028-0.135)</td>
<td>0.057 (0.022-0.105)</td>
<td>0.058 (0.015-0.138)</td>
<td>0.057 (0.016-0.119)</td>
</tr>
<tr>
<td>Year 12 Psychology</td>
<td>0.074 (0.005-0.163)</td>
<td>0.068 (0.024-0.124)</td>
<td>0.069 (0.012-0.192)</td>
<td>0.064 (0.008-0.112)</td>
</tr>
</tbody>
</table>

Table 15

Spearman’s rho correlation coefficients for SES and VCE science subject enrolment proportions.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Correlation with SES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 Biology enrolments</td>
<td>0.08 (285)</td>
</tr>
<tr>
<td>Year 12 Biology enrolments</td>
<td>0.03 (282)</td>
</tr>
<tr>
<td>Year 11 Chemistry enrolments</td>
<td>0.30 (279)</td>
</tr>
<tr>
<td>Year 12 Chemistry enrolments</td>
<td>0.21 (276)</td>
</tr>
<tr>
<td>Year 11 Environmental Science enrolments</td>
<td>0.10 (38)</td>
</tr>
<tr>
<td>Year 12 Environmental Science enrolments</td>
<td>0.16 (41)</td>
</tr>
<tr>
<td>Year 11 Physics enrolments</td>
<td>0.32 (281)</td>
</tr>
<tr>
<td>Year 12 Physics enrolments</td>
<td>0.25 (278)</td>
</tr>
<tr>
<td>Year 11 Psychology enrolments</td>
<td>0.01 (284)</td>
</tr>
<tr>
<td>Year 12 Psychology enrolments</td>
<td>-0.15 (285)</td>
</tr>
</tbody>
</table>


The relationship of SES to technology enrolments

There also appears to be a relationship between SES and pursuing studies in technology. In my paper included in Appendix L, I gave this summary:

In the literature, participation in secondary school technology subjects appears to be associated with coming from a lower SES background. A United Kingdom study suggested that working class students take subjects like home economics and business studies in preferences to languages or history (Davies, Telhaj, Hutton, Adnett, & Coe 2008) and that the SES of the student body influenced the subjects a school offered. Elsworth et al. (1999) found that in Australia lower SES
students were more likely to enrol in computing, home science and technology than their higher SES counterparts. The same study also suggested that a lower average school community SES was also associated with students choosing computing and home science. Dar and Getz (2007) found similar patterns in the choice of tertiary degrees by Israeli students, with lower SES students choosing more practical fields such as engineering and computer science, while higher SES students chose more prestigious courses like medicine and law. In Turkey, Hacifazlioglu (2008) found that students from lower income backgrounds were more likely to pursue engineering, where those from higher income families tended to choose the arts and social sciences. Similarly, in a study in the United States, Mullis, Mullis and Gerweld (1998) showed that students whose parents had unskilled occupations where more likely to be interested in practical and technical careers than those whose parents worked in skilled professions.

Murphy (2019a, p.6, see Appendix L)

This relationship between SES and enrolments is reflected in this study’s findings associated with the technologies component of the school STEM success criteria. Table 16 shows the proportion of enrolments in each of the technology subjects, at schools that offer these subjects, by SES quartile. It shows the highest SES schools had the lowest enrolment proportions in nine of the twelve technology subjects. Further, schools in the first or second quartile for SES had the highest enrolment proportions for nine of the twelve subjects. These findings are in line with previous research findings, contributing to the construct validity of the school STEM enrolment criteria.
Table 16

*Enrolments in VCE technology subjects as a proportion of all VCE subject enrolments by school SES quartile.*

<table>
<thead>
<tr>
<th>Subject</th>
<th>SES Quartile 1 (lowest SES) Mean (Range)</th>
<th>SES Quartile 2 Mean (Range)</th>
<th>SES Quartile 3 Mean (Range)</th>
<th>SES Quartile 4 (highest SES) Mean (Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital technology subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 12 Algorithmics (HESS)</td>
<td>0.001 (0.001 - 0.001)</td>
<td>0.001 (0.001 - 0.001)</td>
<td>0.001 (0.000 - 0.003)</td>
<td>0.005 (0.000 - 0.011)</td>
</tr>
<tr>
<td>Year 11 Information Technology</td>
<td>0.022 (0.000 - 0.036)</td>
<td>0.025 (0.001 - 0.061)</td>
<td>0.018 (0.000 - 0.073)</td>
<td>0.015 (0.000 - 0.048)</td>
</tr>
<tr>
<td>Year 12 Computing: Informatics</td>
<td>0.023 (0.015 - 0.086)</td>
<td>0.016 (0.001 - 0.045)</td>
<td>0.017 (0.001 - 0.084)</td>
<td>0.011 (0.001 - 0.038)</td>
</tr>
<tr>
<td>Year 12 Computing: Software Development</td>
<td>0.008 (0.000 - 0.025)</td>
<td>0.010 (0.020 - 0.025)</td>
<td>0.009 (0.001 - 0.031)</td>
<td>0.008 (0.000 - 0.054)</td>
</tr>
<tr>
<td>Design technology subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 11 Agricultural and Horticultural Studies</td>
<td>0.021 (0.000 - 0.036)</td>
<td>0.025 (0.001 - 0.061)</td>
<td>0.017 (0.000 - 0.042)</td>
<td>0.026 (0.005 - 0.052)</td>
</tr>
<tr>
<td>Year 12 Agricultural and Horticultural Studies</td>
<td>0.035 (0.025 - 0.048)</td>
<td>0.017 (0.020 - 0.046)</td>
<td>0.024 (0.030 - 0.047)</td>
<td>0.021 (0.001 - 0.042)</td>
</tr>
<tr>
<td>Year 11 Food and Technology</td>
<td>0.024 (0.000 - 0.061)</td>
<td>0.031 (0.005 - 0.174)</td>
<td>0.027 (0.001 - 0.098)</td>
<td>0.016 (0.001 - 0.046)</td>
</tr>
<tr>
<td>Year 12 Food and Technology</td>
<td>0.027 (0.010 - 0.070)</td>
<td>0.031 (0.050 - 0.130)</td>
<td>0.024 (0.001 - 0.078)</td>
<td>0.017 (0.001 - 0.048)</td>
</tr>
<tr>
<td>Year 11 Product Design and Technology</td>
<td>0.021 (0.000 - 0.104)</td>
<td>0.032 (0.000 - 0.174)</td>
<td>0.028 (0.002 - 0.082)</td>
<td>0.019 (0.001 - 0.092)</td>
</tr>
<tr>
<td>Year 12 Product Design and Technology</td>
<td>0.024 (0.003 - 0.081)</td>
<td>0.027 (0.001 - 0.087)</td>
<td>0.025 (0.002 - 0.088)</td>
<td>0.018 (0.000 - 0.102)</td>
</tr>
<tr>
<td>Engineering subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 11 Systems Engineering</td>
<td>0.013 (0.000 - 0.038)</td>
<td>0.018 (0.000 - 0.054)</td>
<td>0.015 (0.000 - 0.080)</td>
<td>0.010 (0.000 - 0.032)</td>
</tr>
<tr>
<td>Year 12 Systems Engineering</td>
<td>0.016 (0.001 - 0.040)</td>
<td>0.017 (0.004 - 0.040)</td>
<td>0.015 (0.003 - 0.032)</td>
<td>0.010 (0.000 - 0.024)</td>
</tr>
</tbody>
</table>

5.2.3 Examining the relationship of location to subject enrolment proportions

There is little published research into the impact of location on participation rates in mathematics, science, or technologies. Further, there is only limited research published about the impact of location on student engagement in STEM subjects. Given this, exploring the relationships between location and enrolments in individual STEM subjects cannot contribute to establishing the content validity of the School STEM Success Criteria. However, given the dearth of literature in this area, investigating these relationships can contribute new knowledge to the field.

The relationship of location to mathematics enrolment proportions

There is some limited research into the relationship between location and engagement in mathematics, though this is inconclusive with some studies suggesting that rural students find mathematics less engaging, while others reporting rural students are highly engaged in mathematics (Hardré, 2011). This study did find some variation in enrolment proportions with location in mathematics. In my paper included in Appendix J, I wrote:

Table [17] shows that the enrolment proportion for each of the VCE mathematics subjects varies with location. Enrolment proportions are only calculated using data from schools providing each subject. Table [17] shows the enrolment proportion for the Year 11 level subjects of Foundation Mathematics and General Mathematics is slightly higher in non-metropolitan schools compared to metropolitan schools. It also shows that non-metropolitan schools have a slightly higher enrolment proportion for Year 12 level Further Mathematics than metropolitan schools. However, in the [advanced mathematics] subjects, the pattern is reversed with the enrolment proportion in Year 11 Mathematical Methods being greater in metropolitan schools than non-metropolitan schools. This gap widens further for Year 12 Mathematical Methods. The enrolment proportion in the recently introduced Year 11 Specialist Mathematics is greater in metropolitan schools than non-metropolitan schools. This gap widens for Year 12 Specialist Mathematics.

(Murphy, 2019b, p226-227, see Appendix J)

[These] findings contribute new knowledge to the field. This study found that students in non-metropolitan schools were more likely than metropolitan students to enrol in foundational mathematics subjects at Year 11 and 12. Conversely, they were less likely to have access to the [advanced] mathematics subjects, and where they did have access, they were less likely to enrol in those subjects.

(Murphy, 2019b, p. 231, see Appendix J)
### Table 17

*Enrolments in VCE mathematics subjects as a proportion of all VCE subject enrolments by school location.*

<table>
<thead>
<tr>
<th>Year</th>
<th>Subject</th>
<th>All Schools</th>
<th>Metropolitan Schools</th>
<th>Non-metropolitan Schools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (Range)</td>
<td>Mean (Range)</td>
<td>Mean (Range)</td>
<td></td>
</tr>
<tr>
<td>Year 11</td>
<td>Foundation Mathematics</td>
<td>0.028 (0.000 – 0.112)</td>
<td>0.027 (0.000 – 0.112)</td>
<td>0.030 (0.000 – 0.083)</td>
</tr>
<tr>
<td>Year 11</td>
<td>General Mathematics</td>
<td>0.106 (0.005 – 0.196)</td>
<td>0.100 (0.005 – 0.177)</td>
<td>0.115 (0.058–0.196)</td>
</tr>
<tr>
<td>Year 12</td>
<td>Further Mathematics</td>
<td>0.122 (0.008 – 0.200)</td>
<td>0.114 (0.008 – 0.171)</td>
<td>0.133 (0.071-0.200)</td>
</tr>
<tr>
<td>Year 11</td>
<td>Mathematical Methods</td>
<td>0.051 (0.004 – 0.172)</td>
<td>0.057 (0.007 – 0.172)</td>
<td>0.045 (0.004-0.103)</td>
</tr>
<tr>
<td>Year 12</td>
<td>Mathematical Methods</td>
<td>0.045 (0.004 – 0.155)</td>
<td>0.051 (0.004 – 0.155)</td>
<td>0.037 (0.004-0.103)</td>
</tr>
<tr>
<td>Year 11</td>
<td>Specialist Mathematics</td>
<td>0.007 (0.000 – 0.037)</td>
<td>0.008 (0.000 – 0.037)</td>
<td>0.005 (0.001–0.026)</td>
</tr>
<tr>
<td>Year 12</td>
<td>Specialist Mathematics</td>
<td>0.014 (0.001 – 0.075)</td>
<td>0.017 (0.001 – 0.075)</td>
<td>0.010 (0.001-0.028)</td>
</tr>
</tbody>
</table>


As the literature about the impact of location on student enrolment and engagement in mathematics is limited, as well as inconclusive, it is my that this study’s findings of enrolment proportion variance in VCE mathematics with location should not be seen as in conflict or aligned with previous research, but as a new contribution to the literature. Given this, these findings cannot be seen as either strengthening or weakening the construct validity of the school STEM enrolment criteria.

**The relationship of location to science enrolment proportions**

There is only limited evidence suggesting location impacts engagement in science. In my paper included in Appendix K, I summarised this:

Metropolitan students were more likely to report an interest in science and enjoyment in learning science (Thomson et al. 2017a). In contrast, students attending small rural or remote schools were
less likely to enjoy science subjects or to prefer science subjects to other subjects (Lyons and Quinn 2010).

(Murphy, 2018a, p. 7, see Appendix K)

However, this relationship between location and engagement is not strongly reflected in the findings associated with the science enrolments in this study. I summarised these findings in my paper included in Appendix K:

Table [18] lists the mean enrolment proportions and the range of enrolment proportions for each of the VCE studies by location… The enrolment proportions of some sciences vary to some degree with location. Chemistry attracts slightly more enrolments in metropolitan schools than in non-metropolitan schools, while the reverse is true for Biology and Environmental Science.

(Murphy, 2018a, p. 9, see Appendix K)

While these enrolment proportions show some slight differences in enrolment proportion by location for individual science subjects, there is no clear trend suggesting that these findings align or contradict previous research suggesting rural students find sciences less engaging. Given this, these findings do not contribute to establishing the construct validity of the school STEM enrolment criteria, however it cannot be said that they weaken the validity either.

The relationship of location to technology enrolment proportions
There is a dearth of published research examining the impact of location on enrolment or engagement with technology subjects. The findings of this study suggests some relationship between location and enrolment in senior technology subjects. In my paper included in Appendix L, I wrote:

Table [19] shows the enrolment proportions in VCE technology subjects in schools where each subject is offered by school location. This shows the design technologies tend to attract higher enrolment proportions than the digital technologies and engineering. Not only are non-metropolitan schools more likely to provide Agricultural and Horticultural Studies, Product Design and Technology, and Systems Engineering, when they are provided, students in nonmetropolitan schools enrol in higher proportions. Despite Food and Technology being more likely to be offered in metropolitan schools, where it is offered in non-metropolitan schools students enrol in greater proportions. Also, despite digital technologies being less likely to be
provided in non-metropolitan locations, these students enrol in similar proportions to their metropolitan counterparts.

(Murphy, 2019a, p. 9, see Appendix L)

Given the lack of research published about the impact of location on participation in senior technologies, these finding do not contribute to the validation of the school STEM success criteria, but do represent new knowledge.

Table 18

*Enrolments in VCE science subjects as a proportion of all VCE subject enrolments by school location.*

<table>
<thead>
<tr>
<th></th>
<th>All Schools</th>
<th>Metropolitan Schools (N=164)</th>
<th>Non-metropolitan Schools (N=122)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 Biology</td>
<td>0.049</td>
<td>0.047</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td>(0.003 – 0.136)</td>
<td>(0.003 – 0.136)</td>
<td>(0.024 – 0.101)</td>
</tr>
<tr>
<td>Year 12 Biology</td>
<td>0.052</td>
<td>0.050</td>
<td>0.055</td>
</tr>
<tr>
<td></td>
<td>(0.015 – 0.163)</td>
<td>(0.017 – 0.163)</td>
<td>(0.015 – 0.130)</td>
</tr>
<tr>
<td>Year 11 Chemistry</td>
<td>0.036</td>
<td>0.039</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td>(0.002 – 0.167)</td>
<td>(0.002 – 0.167)</td>
<td>(0.002 – 0.084)</td>
</tr>
<tr>
<td>Year 12 Chemistry</td>
<td>0.031</td>
<td>0.033</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td>(0.004 – 0.161)</td>
<td>(0.005 – 0.161)</td>
<td>(0.004 – 0.058)</td>
</tr>
<tr>
<td>Year 11 Environmental Science</td>
<td>0.009</td>
<td>0.008</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td>(0.000 – 0.050)</td>
<td>(0.000 – 0.050)</td>
<td>(0.002 – 0.049)</td>
</tr>
<tr>
<td>Year 12 Environmental Science</td>
<td>0.015</td>
<td>0.013</td>
<td>0.017</td>
</tr>
<tr>
<td></td>
<td>(0.000 – 0.098)</td>
<td>(0.000 – 0.098)</td>
<td>(0.001 – 0.070)</td>
</tr>
<tr>
<td>Year 11 Physics</td>
<td>0.027</td>
<td>0.028</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>(0.001 – 0.074)</td>
<td>(0.001 – 0.074)</td>
<td>(0.003 – 0.073)</td>
</tr>
<tr>
<td>Year 12 Physics</td>
<td>0.026</td>
<td>0.027</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>(0.003 – 0.083)</td>
<td>(0.003 – 0.078)</td>
<td>(0.003 – 0.083)</td>
</tr>
<tr>
<td>Year 11 Psychology</td>
<td>0.058</td>
<td>0.059</td>
<td>0.057</td>
</tr>
<tr>
<td></td>
<td>(0.015 – 0.138)</td>
<td>(0.016 – 0.138)</td>
<td>(0.015 – 0.135)</td>
</tr>
<tr>
<td>Year 12 Psychology</td>
<td>0.069</td>
<td>0.069</td>
<td>0.069</td>
</tr>
<tr>
<td></td>
<td>(0.005 – 0.192)</td>
<td>(0.005 – 0.192)</td>
<td>(0.008 – 0.163)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year 12 Algorithmics (HESS)</th>
<th>Year 11 Information Technology</th>
<th>Year 12 Computing: Informatics</th>
<th>Year 12 Computing: Software Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003 (0.000 - 0.011)</td>
<td>0.018 (0.000 - 0.079)</td>
<td>0.017 (0.000 - 0.086)</td>
<td>0.009 (0.000 - 0.054)</td>
</tr>
<tr>
<td>0.004 (0.000 - 0.011)</td>
<td>0.019 (0.000 - 0.079)</td>
<td>0.018 (0.000 - 0.086)</td>
<td>0.009 (0.000 - 0.054)</td>
</tr>
<tr>
<td>0.002 (0.000 - 0.003)</td>
<td>0.016 (0.000 - 0.073)</td>
<td>0.016 (0.001 - 0.082)</td>
<td>0.009 (0.000 - 0.034)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year 11 Agricultural and Horticultural Studies</th>
<th>Year 12 Agricultural and Horticultural Studies</th>
<th>Year 11 Food and Technology</th>
<th>Year 12 Food and Technology</th>
<th>Year 11 Product Design and Technology</th>
<th>Year 12 Product Design and Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.021 (0.000 - 0.061)</td>
<td>0.022 (0.000 - 0.048)</td>
<td>0.025 (0.000 - 0.174)</td>
<td>0.025 (0.001 - 0.130)</td>
<td>0.025 (0.000 - 0.174)</td>
<td>0.024 (0.000 - 10.002)</td>
</tr>
<tr>
<td>0.016 (0.001 - 0.052)</td>
<td>0.008 (0.000 - 0.021)</td>
<td>0.020 (0.000 - 0.058)</td>
<td>0.020 (0.001 - 0.070)</td>
<td>0.016 (0.000 - 0.051)</td>
<td>0.016 (0.000 - 0.061)</td>
</tr>
<tr>
<td>0.022 (0.000 - 0.061)</td>
<td>0.024 (0.000 - 0.048)</td>
<td>0.032 (0.000 - 0.174)</td>
<td>0.031 (0.001 - 0.130)</td>
<td>0.036 (0.000 - 0.174)</td>
<td>0.033 (0.001 - 10.002)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engineering subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 Systems Engineering</td>
</tr>
<tr>
<td>0.014 (0.000 - 8.0%)</td>
</tr>
<tr>
<td>0.010 (0.000 - 0.032)</td>
</tr>
<tr>
<td>0.020 (0.000 – 0.080)</td>
</tr>
</tbody>
</table>

5.2.4 Examining the relationship of SES to the STEM achievement criterion

There is a weight of research showing a positive correlation between SES and student achievement in STEM subjects (ACARA, 2018; Connolly, 2017b; Thomson, De Bortoli, & Underwood, 2017; Thomson, Wernert, et al., 2017). Given this, it would be anticipated that the STEM achievement criterion of the School STEM Success Criteria, would positively correlate with socioeconomic status. This was investigated by calculating a Spearman’s rho correlation coefficient. It was found that there was a strong positive correlation (Prion & Haerling, 2014) between SES and mean STEM achievement level ($\rho = 0.61$), supporting the construct validity of this criterion.

Research on the relationships between SES and achievement level tends to consider the STEM disciplines separately. What follows is a discussion of how achievement levels in each subject area varied with SES, and the relative alignment of these findings with the published literature; thus supporting the construct validity of the school STEM success criteria.

The relationship of SES to achievement in mathematics

There is a well-researched correlation between Australian students’ socioeconomic status and achievement in mathematics. In my paper included in Appendix J, I presented this overview:

The 2015 PISA testing showed year 9 students from the highest SES quartile were on average 3 years ahead of those from the lowest SES quartile (Thomson, De Bortoli, et al. 2017). The TIMSS uses several indicators of SES, including the number of books in the home, the education resources in the home and the educational level of parents, and found that all three correlated strongly with achievement (Thomson et al. 2017a). A similar association between SES and achievement was revealed through the National Assessment Programme’s (NAP) numeracy testing. Year 9 students achieve better in numeracy testing if their parents have higher levels of education and if their parents work in higher occupation levels (ACARA 2017). These findings reflect the relationship between SES and mathematics achievement that has been well-researched internationally (Grootenboer and Hemmings 2007; Kalaycioglu 2015; Rothman 2003; Weber et al. 2010).

(Murphy, 2019b, p. 222, see Appendix J)
This relationship between SES and achievement level is reflected in the findings associated with the mathematics component of the STEM achievement criterion. I described these findings in my paper included in Appendix J:

Table [20] … shows that achievement levels in each of the VCE mathematics subjects … varies with [SES]. Year 12 VCE mathematics performance decreases across the [SES] quartiles in all three subjects. In Further Mathematics, Mathematical Methods, and Specialist Mathematics, first quartile [SES] schools’ average study scores are 4.52, 4.55 and 3.54 points [lower] than that of fourth quartile schools in these subjects respectively.

The relationship between [SES] and achievement level was investigated by calculating Spearman’s rho correlation coefficients for each subject, across all schools … As can be seen in Table [21], there is a moderate [positive] correlation between [SES] and achievement across all schools in Further Mathematics ($\rho = 0.496$) and Mathematical Methods ($\rho = 0.482$), and a weaker moderate [positive] correlation in Specialist Mathematics ($\rho = 0.390$).

Murphy (2019b, p. 230, see Appendix J)

Combined, these findings suggest that the mathematics achievement levels, used as part of the school STEM achievement criterion, vary with SES in ways that align with previous findings, contributing to the construct validity of that criterion.

**Table 20**

*Comparison of schools’ achievement levels in VCE Year 12 mathematics subjects, where results were available for 2014, 2015 and 2016, by SES quartile*

<table>
<thead>
<tr>
<th>Subject</th>
<th>SES Quartile 1 (lowest SES)</th>
<th>SES Quartile 2</th>
<th>SES Quartile 3</th>
<th>SES Quartile 4 (highest SES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Further Mathematics</td>
<td>47 25.88 (19.50-35.67)</td>
<td>53 27.12 (18.36-31.99)</td>
<td>54 27.73 (21.11-32.33)</td>
<td>68 30.264 (23.00-41.21)</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>47 24.74 (18.44-31.00)</td>
<td>52 25.59 (16.96-32.34)</td>
<td>54 26.36 (21.21-33.09)</td>
<td>68 28.75 (18.80-37.32)</td>
</tr>
<tr>
<td>Specialist Mathematics</td>
<td>47 24.78 (17.08-35.00)</td>
<td>53 26.73 (18.00-46.00)</td>
<td>54 26.14 (17.71-33.00)</td>
<td>68 28.32 (17.00-36.31)</td>
</tr>
</tbody>
</table>

Table 21

Spearman’s rho correlation coefficients for SES and VCE Year 12 mathematics subject achievement levels in all schools

<table>
<thead>
<tr>
<th>Subject</th>
<th>Correlation with SES $r_s$ (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 12 Further Mathematics achievement</td>
<td>0.496 (284)</td>
</tr>
<tr>
<td>Year 12 Mathematical Methods achievement</td>
<td>0.482 (280)</td>
</tr>
<tr>
<td>Year 12 Specialist Mathematics achievement</td>
<td>0.390 (226)</td>
</tr>
</tbody>
</table>


The relationship of SES to achievement in sciences

Similar to mathematics, there is a well-researched relationship between Australian students’ socioeconomic status and achievement in science. In my paper included in Appendix K I wrote:

In Australia, SES appears to impact science achievement (Thomson et al. 2017a, b). The TIMSS uses a variety of indicators of SES and all show correlation with science achievement, with students with fewer books, fewer educational resources, and parents with lower levels of education, all performing more poorly in science than their more advantaged counterparts (Thomson et al. 2017b). In the 2015 PISA tests of scientific literacy, the gap between the lowest and highest SES students was 91 points, and the gap between each SES quartile was equivalent to one year of schooling (Thomson et al. 2017a). Unfortunately, Australia is part of an international trend, as SES appears to impact significantly on science achievement (OECD 2018). Across all OECD countries, disadvantaged students scored on average 88 points less than advantaged students in the 2015 PISA tests.

(Murphy, 2018a, p. 6, see Appendix K)

This relationship between SES and achievement level is reflected in the findings associated with the science component of the school STEM success criteria. I described these findings in my paper included in Appendix K:
Table [22] lists the mean study score and range of study scores for each science subject, by SES quartile. It shows that achievement levels in the sciences vary considerably with SES. In Biology, Chemistry, Environmental Science, Physics and Psychology, the highest SES school’s average study scores are 5.03, 4.63, 8.85, 4.03 and 4.85 points higher than that of the lowest SES schools in these subjects respectively.

Spearman’s rho correlation coefficients were also calculated to explore the relationship between SFOE and achievement levels. Table [23] lists the correlation coefficients for each subject, across all schools... As can be seen in Table [22], there is a large [positive] correlation between SES and achievement across all schools in all of the Science subjects, except for Physics where there is a medium to large correlation.

Combined, these findings suggest that the science achievement levels, used as part of the school STEM achievement criterion, vary with SES in ways that align with previous research findings, contributing to the construct validity of that criterion.

Table 22

Comparison of schools’ achievement levels in VCE Year 12 science subjects, where results were available for 2014, 2015 and 2016, by SES quartile

<table>
<thead>
<tr>
<th>Subject</th>
<th>SES Quartile 1 (lowest SES)</th>
<th>SES Quartile 2</th>
<th>SES Quartile 3</th>
<th>SES Quartile 4 (highest SES)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (Range)</td>
<td>Mean (Range)</td>
<td>Mean (Range)</td>
</tr>
<tr>
<td>Biology</td>
<td>69</td>
<td>24.89 (16.00-31.71)</td>
<td>26.09 (19.09-31.44)</td>
<td>27.65 (23.00-33.08)</td>
</tr>
<tr>
<td>Chemistry</td>
<td>67</td>
<td>24.51 (15.00-31.50)</td>
<td>25.10 (17.00-31.88)</td>
<td>26.86 (19.33-34.00)</td>
</tr>
<tr>
<td>Environmental Science</td>
<td>5</td>
<td>22.88 (19.36-27.19)</td>
<td>27.12 (25.00-29.00)</td>
<td>28.78 (21.50-43.00)</td>
</tr>
<tr>
<td>Physics</td>
<td>66</td>
<td>25.41 (16.00-35.00)</td>
<td>26.33 (18.00-34.00)</td>
<td>27.46 (11.67-37.00)</td>
</tr>
<tr>
<td>Psychology</td>
<td>70</td>
<td>25.63 (15.22-33.94)</td>
<td>26.86 (19.52-39.00)</td>
<td>28.30 (21.79-36.00)</td>
</tr>
</tbody>
</table>

Table 23

*Spearman’s rho correlation coefficients for SES and VCE Year 12 science subject achievement levels*

<table>
<thead>
<tr>
<th>Subject</th>
<th>r, (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td>0.56 (282)</td>
</tr>
<tr>
<td>Chemistry</td>
<td>0.51 (276)</td>
</tr>
<tr>
<td>Environmental Science</td>
<td>0.56 (37)</td>
</tr>
<tr>
<td>Physics</td>
<td>0.45 (278)</td>
</tr>
<tr>
<td>Psychology</td>
<td>0.59 (284)</td>
</tr>
</tbody>
</table>


**The relationship of SES to achievement in technologies**

As in mathematics and science, there is a known relationship between students’ socioeconomic status and achievement in technology, however this relationship has had relatively limited exploration. I summarised this limited evidence base in my paper included in Appendix L:

The United States’ Technology and Engineering Literacy (TEL) assessment of 2014 reported average student performance correlated positively with parental education level and negatively with student eligibility for the national school lunch program (National Assessment of Educational Progress [NAEP] 2014). Ritzhaupt et al. (2013) also found that US students from high SES backgrounds had stronger ICT literacy skills than those from low SES backgrounds. Australia’s National Assessment Program revealed that SES and ICT literacy were positively correlated for Australian Year 6 and 10 students, with parental occupation and education levels both impacting strongly on students’ average results (ACARA 2014).

(Murphy, 2019a, p. 6, see Appendix L)

This relationship between SES and achievement level is reflected in the findings associated with the technology component of the school STEM success criteria. I described these findings in my paper included in Appendix L:
Table [24] shows school’s mean study scores in each of the Year 12 technology subjects by SES quartile. In all subjects except Agricultural and Horticultural Studies and Systems Engineering, mean study score increased as SES quartile increased. In Systems Engineering the scores of the first two quartiles were lowest and scores increased from there into the third and fourth quartile. In Agricultural and Horticultural studies the lowest SES schools achieved highest and the highest SES schools achieved lowest however this was based on four and three schools respectively. Given these low numbers this trend may not be a reliable indicator of general performance.

Table [25] provides data about the relationship between SES and achievement level by listing Spearman’s rho correlation coefficients for each subject, across all schools. It shows there is a small positive linear correlation between SES and achievement for most subjects, with a large positive correlation in Food and Technology, and a negligible correlation in Agricultural and Horticultural studies.

(Murphy, 2019a, p. 11, see Appendix L)

Combined, these findings suggest that the technology achievement levels, used as part of the school STEM achievement criterion, generally varied with SES in ways that align with previous findings, contributing to the construct validity of that criterion.

5.2.5 Examining the relationship of location to STEM achievement level

There is also substantial evidence that STEM achievement level varies with location (ACARA, 2018; Connolly, 2017b; Thomson, De Bortoli, & Underwood, 2017; Thomson, Wernert, et al., 2017). Given this, it would be anticipated that the composite variable STEM achievement level would vary with school location. As anticipated, there was a difference in the average achievement between metropolitan and nonmetropolitan schools, with mean achievement levels of 27.58 and 26.88 respectively, supporting the construct validity of the school STEM achievement criterion.

Research on the relationships between location and achievement level tends to consider the STEM disciplines separately. What follows is a discussion of how achievement levels in each subject area vary with location, and the relative alignment of these findings with previously published literature, thus further building the argument for the construct validity of the school STEM success criteria.
Table 24

Comparison of schools’ achievement levels in VCE Year 12 technology subjects, where results were available for 2014, 2015 and 2016, by SES quartile

<table>
<thead>
<tr>
<th>Subject</th>
<th>SES Quartile 1 (lowest SES)</th>
<th>SES Quartile 2</th>
<th>SES Quartile 3</th>
<th>SES Quartile 4 (highest SES)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (Range)</td>
<td>N</td>
<td>Mean (Range)</td>
</tr>
<tr>
<td>Digital technology subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algorithmics (HESS)</td>
<td>1</td>
<td>28.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(26.00-38.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computing: Informatics</td>
<td>55</td>
<td>27.00 (20.32-36.33)</td>
<td>41</td>
<td>28.84 (22.25-47.00)</td>
</tr>
<tr>
<td>Computing: Software Development</td>
<td>21</td>
<td>27.25 (18.20-36.00)</td>
<td>32</td>
<td>27.58 (14.50-43.00)</td>
</tr>
<tr>
<td>Design technology subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural and Horticultural Studies</td>
<td>4</td>
<td>30.94 (26.75-39.00)</td>
<td>9</td>
<td>29.58 (20.14-40.00)</td>
</tr>
<tr>
<td>Food and Technology</td>
<td>53</td>
<td>25.93 (14.25-32.95)</td>
<td>64</td>
<td>28.17 (18.50-35.00)</td>
</tr>
<tr>
<td>Product Design and Technology</td>
<td>37</td>
<td>25.52 (9.32-35.00)</td>
<td>54</td>
<td>27.04 (11.67-41.50)</td>
</tr>
<tr>
<td>Engineering subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systems Engineering</td>
<td>14</td>
<td>27.44 (20.38-35.90)</td>
<td>24</td>
<td>27.43 (21.08-32.79)</td>
</tr>
</tbody>
</table>

Table 25

Spearman’s rho correlation coefficients for SES and VCE Year 12 technology subject achievement levels

<table>
<thead>
<tr>
<th>Subjects</th>
<th>r, (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital technology subjects</td>
<td></td>
</tr>
<tr>
<td>Algorithmics (HESS)</td>
<td>0.25 (13)</td>
</tr>
<tr>
<td>Computing: Informatics</td>
<td>0.28 (162)</td>
</tr>
<tr>
<td>Computing: Software Development</td>
<td>0.28 (128)</td>
</tr>
<tr>
<td>Design technology subjects</td>
<td></td>
</tr>
<tr>
<td>Agricultural and Horticultural Studies</td>
<td>-0.07 (29)</td>
</tr>
<tr>
<td>Food and Technology</td>
<td>0.51 (231)</td>
</tr>
<tr>
<td>Product Design and Technology</td>
<td>0.28 (190)</td>
</tr>
<tr>
<td>Engineering subjects</td>
<td></td>
</tr>
<tr>
<td>Systems Engineering</td>
<td>0.33 (75)</td>
</tr>
</tbody>
</table>


The relationship of location to achievement in mathematics

There is a well-researched relationship between Australian students’ location and their achievement in mathematics. In my paper included in Appendix J, I gave this brief overview:

The TIMSS demonstrates that metropolitan year 8 students significantly outperform students from provincial schools who, in turn, outperform students from remote areas (Thomson et al. 2017b). PISA testing shows metropolitan year 9 students’ mathematical literacy is significantly higher than the OECD average and nonmetropolitan year 9 students’ is significantly lower, with the gap between the two being the equivalent of more than a year of learning (Thomson et al. 2017a). This pattern is also borne out by national numeracy testing (ACARA 2017).

(Murphy, 2019b, p. 222, see Appendix J)
This relationship between location and achievement level is reflected in the findings associated with the mathematics component of the school STEM achievement criterion. I described these findings in the paper included in Appendix J:

Table [26] shows that achievement levels in each of the VCE mathematics subjects varies with location. Metropolitan schools outperform non-metropolitan schools in all three Year 12 VCE mathematics subjects. Metropolitan schools’ average (mean) study scores are 0.83, 1.67 and 1.82 points higher than that of non-metropolitan schools’ in Further Mathematics, Mathematical Methods, and Specialist Mathematics respectively.

(Murphy, 2019b, p. 229, see Appendix J)

These findings suggest that the mathematics achievement levels vary with location in line with previous findings, thus contributing to the construct validity of the school STEM achievement criterion.

Table 26
Comparison of schools’ median achievement levels in VCE Year 12 mathematics subjects, where results were available for 2014, 2015 and 2016, by location

<table>
<thead>
<tr>
<th></th>
<th>All Schools</th>
<th>Metropolitan Schools</th>
<th>Non-metropolitan Schools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (Range)</td>
<td>N</td>
</tr>
<tr>
<td>Further Mathematics</td>
<td>222</td>
<td>27.97 (18.36-41.21)</td>
<td>139</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>221</td>
<td>26.57 (16.96-37.32)</td>
<td>139</td>
</tr>
<tr>
<td>Specialist Mathematics</td>
<td>222</td>
<td>26.66 (17.00-46.00)</td>
<td>139</td>
</tr>
</tbody>
</table>


The relationship of location to achievement in sciences
There is also a well-researched relationship between Australian students’ location and their achievement in science. In my paper included in Appendix K I gave this brief summary:

Both PISA testing and TIMSS testing suggest that Australian students in metropolitan schools significantly outperform students from non-metropolitan schools in science achievement
(Thomson et al. 2017a, b), with PISA testing suggesting the divide is the equivalent of at least one year of schooling (Thomson et al. 2017a). National testing of scientific literacy reveals a similar pattern of achievement (Connolly 2017). The 2015 PISA survey of Australian students’ motivations and beliefs in science revealed that metropolitan students were more likely to view science as contributing to their career pathway and job prospects.

(Murphy, 2018a, pp. 6-7, see Appendix K)

This relationship between location and achievement level is reflected in the findings associated with the sciences component of the school STEM achievement criterion. I described these findings in the paper included in Appendix K:

Table [27] lists the mean study score and range of study scores for each science subject, achieved in all schools, metropolitan schools and non-metropolitan schools. It shows that on average, students in metropolitan schools achieve higher study scores in all the sciences than students in non-metropolitan schools. However, the margins are all less than 1 study score point, being 0.79, 0.60, 0.36, 0.54, [and] 0.93 for Biology, Chemistry, Environmental Science, Physics and Psychology respectively.

(Murphy, 2018a, p. 12, see Appendix K)

Table 27

Comparison of schools’ achievement levels in VCE Year 12 science subjects, where results were available for 2014, 2015 and 2016, by location

<table>
<thead>
<tr>
<th></th>
<th>All Schools</th>
<th>Metropolitan Schools</th>
<th>Non-metropolitan Schools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (Range)</td>
<td>N</td>
</tr>
<tr>
<td>Biology</td>
<td>282</td>
<td>27.16 (16.00-41.31)</td>
<td>160</td>
</tr>
<tr>
<td>Chemistry</td>
<td>276</td>
<td>26.43 (15.00-35.69)</td>
<td>159</td>
</tr>
<tr>
<td>Environmental Science</td>
<td>37</td>
<td>28.39 (19.36-43.00)</td>
<td>20</td>
</tr>
<tr>
<td>Physics</td>
<td>278</td>
<td>27.20 (11.67-37.53)</td>
<td>160</td>
</tr>
<tr>
<td>Psychology</td>
<td>284</td>
<td>27.82 (15.22-39.92)</td>
<td>163</td>
</tr>
</tbody>
</table>

These findings suggest that the science achievement levels vary with location in line with previous findings, further contributing to the construct validity of the school STEM achievement criterion.

**The relationship of location to achievement in technologies**

There is limited, and somewhat mixed, evidence that student location impacts their achievement in technologies. In my paper included in Appendix L I gave this brief overview:

In the USA, the Technology and Engineering Literacy (TEL) assessment showed students from cities scored more poorly than other students in technology and engineering literacy, compared to suburban, town or rurally located students (NAEP 2014). However, in Australia, students from metropolitan schools significantly outperformed students from provincial areas, who in turn out performed students from remote schools, in ICT literacy (ACARA 2014).

(Murphy, 2019a, p. 6, see Appendix L)

The relationships between location and achievement level in the various technologies subjects studied in this study were found to be similarly mixed. I described these findings in the paper included in Appendix L:

Table [28] shows the range and mean of Year 12 study scores achieved in technology subjects in all schools, metropolitan schools and non-metropolitan schools across the three years of the study. It shows that mean study scores in metropolitan schools and non-metropolitan schools are similar in most subjects. However, there are three subjects with large differences in mean study score by location. Metropolitan schools achieve higher scores in both Computing: Software Development and Product Design and Technology. Non-metropolitan schools earn better results in Agriculture and Horticulture, though it should be noted that only three metropolitan schools ran this subject during the study period. (pp. 9-11)

(Murphy, 2019a, pp. 9-11, see Appendix L)

These findings do not substantially contradict nor align with what is already represented in the limited published literature on the relationship of location to achievement in technologies. Thus, they cannot be said to strengthen or weaken the construct validity of the school STEM achievement criterion.
Table 28
Comparison of schools’ achievement levels in VCE Year 12 technology subjects, where results were available for 2014, 2015 and 2016, by location

<table>
<thead>
<tr>
<th>Subject</th>
<th>All Schools</th>
<th>Metropolitan Schools</th>
<th>Non-metropolitan Schools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (Range)</td>
<td>N</td>
</tr>
<tr>
<td>Digital technology subjects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algorithmics (HESS)</td>
<td>13</td>
<td>31.46 (23.71-41.00)</td>
<td>9</td>
</tr>
<tr>
<td>Computing: Informatics</td>
<td>162</td>
<td>28.27 (14.50-47.00)</td>
<td>103</td>
</tr>
<tr>
<td>Computing: Software Development</td>
<td>128</td>
<td>28.64 (13.50-44.00)</td>
<td>81</td>
</tr>
<tr>
<td>Design technology subjects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural and Horticultural Studies</td>
<td>29</td>
<td>29.54 (12.00-40.00)</td>
<td>3</td>
</tr>
<tr>
<td>Food and Technology</td>
<td>231</td>
<td>28.71 (14.25-41.00)</td>
<td>136</td>
</tr>
<tr>
<td>Product Design and Technology</td>
<td>190</td>
<td>27.42 (9.32-50.00)</td>
<td>103</td>
</tr>
<tr>
<td>Engineering subjects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systems Engineering</td>
<td>75</td>
<td>29.07 (18.95-50.00)</td>
<td>41</td>
</tr>
</tbody>
</table>


5.3 Identification of high STEM performing schools
For the purpose of identifying potential participant-schools for Phase Two, schools were deemed to be high STEM performing if they performed better than the average of their like-school group for each of the three School STEM Success Criteria. To reiterate, these criteria are:
1. Mean school enrolment proportions in STEM subjects at Year 11 level across 2014, 2015, and 2016;
2. Mean school enrolment proportions in STEM subjects at Year 12 level across 2014, 2015, and 2016; and

Like-school groups were comprised of schools in similar locations (either metropolitan or non-metropolitan) and in the same SES quartile. As explained in Section 4.4.3, all schools were divided into one of eight like-school groups using their location and then their SES. The mean STEM enrolment proportions at Year 11 and Year 12 and the mean STEM achievement levels for each of these like-school groups were calculated. To meet each respective criterion, a school needed to have a score (enrolment proportion or achievement level) above the like-school group mean. These means are displayed in Table 29.

**Table 29**

*Mean Year 11 STEM enrolment proportion, Year 12 STEM enrolment proportion, and STEM achievement level for each like-school group.*

<table>
<thead>
<tr>
<th>Like-school group</th>
<th>N</th>
<th>Mean Year 11 STEM enrolment proportion</th>
<th>Mean Year 12 STEM enrolment proportion</th>
<th>Mean Year 12 STEM achievement level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropolitan schools</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS1</td>
<td>41</td>
<td>0.40</td>
<td>0.40</td>
<td>25.00</td>
</tr>
<tr>
<td>MS2</td>
<td>41</td>
<td>0.39</td>
<td>0.39</td>
<td>26.29</td>
</tr>
<tr>
<td>MS3</td>
<td>41</td>
<td>0.40</td>
<td>0.41</td>
<td>28.06</td>
</tr>
<tr>
<td>MS4</td>
<td>41</td>
<td>0.42</td>
<td>0.42</td>
<td>30.92</td>
</tr>
<tr>
<td>Non-metropolitan schools</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMS1</td>
<td>31</td>
<td>0.42</td>
<td>0.42</td>
<td>25.71</td>
</tr>
<tr>
<td>NMS2</td>
<td>30</td>
<td>0.43</td>
<td>0.43</td>
<td>26.72</td>
</tr>
<tr>
<td>NMS3</td>
<td>30</td>
<td>0.43</td>
<td>0.44</td>
<td>27.33</td>
</tr>
<tr>
<td>NMS4</td>
<td>31</td>
<td>0.42</td>
<td>0.40</td>
<td>27.77</td>
</tr>
</tbody>
</table>

Each school’s mean for each School STEM Success Criterion was compared to the like-school group mean score for that criterion. A school was deemed to meet a criterion when the school’s score exceeded the like-school group mean for that criterion. For example,
a school in like-school group NMS2 (Non-metropolitan School, Second SES quartile) with a mean Year 11 enrolment proportion of 0.45, which exceeds the like-school group mean of 0.43, would meet the first School STEM Success Criterion. If the same school had a mean Year 12 achievement level of 26.70, which is lower than the like-school group mean of 26.72, it would not meet the third School STEM Success Criterion.

Table 30 shows the number schools in each like-school group that met none, one, two, or all of the school STEM success criteria. This table shows that 64 of all schools, including 35 metropolitan schools and 29 non-metropolitan schools, did not meet any of the School STEM Success Criteria. The majority of schools, 158 in total, met just one or two criteria. Only 64 schools met all three criteria, and were thus deemed to be relatively high STEM performing. This means that just 22% of Victorian government secondary schools were deemed relatively high STEM performing in this study. As Table 30 shows, 39 metropolitan schools and 25 non-metropolitan schools were categorised as high STEM performing.

Table 30

Number of schools in each like-school group that meet zero, one, two, or three of the School STEM Success Criteria.

<table>
<thead>
<tr>
<th>Like-school group</th>
<th>N</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropolitan schools</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS1</td>
<td>41</td>
<td>14</td>
<td>8</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>MS2</td>
<td>41</td>
<td>7</td>
<td>10</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>MS3</td>
<td>41</td>
<td>6</td>
<td>14</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>MS4</td>
<td>41</td>
<td>8</td>
<td>11</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>All metropolitan schools</td>
<td>164</td>
<td>35</td>
<td>43</td>
<td>47</td>
<td>39</td>
</tr>
<tr>
<td>Non-metropolitan schools</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMS1</td>
<td>31</td>
<td>10</td>
<td>9</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>NMS2</td>
<td>30</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>NMS3</td>
<td>30</td>
<td>6</td>
<td>10</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>NMS4</td>
<td>31</td>
<td>6</td>
<td>9</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>All non-metropolitan schools</td>
<td>122</td>
<td>29</td>
<td>36</td>
<td>32</td>
<td>25</td>
</tr>
<tr>
<td>All schools</td>
<td>286</td>
<td>64</td>
<td>79</td>
<td>79</td>
<td>64</td>
</tr>
</tbody>
</table>

As agreed with the DET Victoria prior to the commencement of Phase One, the high STEM performing non-metropolitan schools were re-identified in order that they could be
considered as potential participants in Phase Two. Six of these schools were located in a regional city. As discussed in the Methodology chapter (Section 4.5.1 Site Selection), these schools were not eligible for inclusion in Phase Two.

The remaining 19 schools, located in rural towns, were considered as potential case study schools for Phase Two. All bar two of these schools had student populations of fewer than 350 students, while the other two schools were significantly larger, one with more than 550 students, and the other with more than 900 students. Eleven of these schools were P-12 schools catering for students from the beginning of primary school through to Year 12, while the other schools were straight secondary schools with students from Year 7 to 12. The P-12 schools all had student populations of less than 350 students. All the schools had 11% or smaller proportions of students with language backgrounds other than English, with all but three of the schools having a proportion of 4% or less, far lower than the Victorian School average of 18% (DET Victoria, 2019). In 14 of the 19 schools, the proportion of students identifying as Indigenous Australian or Torres Strait Islander was equal to or higher than the average Victorian government secondary school of 2% (ACARA, 2019).

5.4 Summary

This chapter has established the construct validity of the criteria used to measure the relative STEM success of each Victorian government school. School performance against these criteria, and elements of these criteria, were compared to the performance that would be predicted by theory. Previous research has found that student SES influences student enrolment choices and engagement in STEM, with students from higher SES backgrounds most likely to choose more advanced mathematics, chemistry, and physics, and least likely to choose technology subjects. The findings presented in this chapter show a similar pattern, contributing to the construct validity of the first and second School STEM Success Criteria. Previous research suggests that student achievement in STEM is positively correlated with SES. The research presented in this chapter found that achievement in STEM positively correlated with school SES in fourteen of the fifteen Year 12 STEM subjects offered in the VCE. Similarly, previous research suggests that location impacts STEM achievement. The findings of this research reflected this, with metropolitan schools outperforming nonmetropolitan schools in thirteen of the fifteen Year 12 VCE STEM subjects. These achievement related findings contribute to the construct validity of the third School STEM Success Criterion. Collectively, the Phase One analyses presented in this chapter suggest that
the School STEM Success Criteria have sound construct validity, supporting their use as a means to judge the relative STEM success of Victorian government secondary schools.

After establishing the construct validity of the School STEM Success Criteria, this chapter reported the criterion-specific thresholds schools were required to exceed if they were to be judged as high performing. Schools were said to meet any one criterion if they exceeded the mean score for their like-school group – all schools in a similar location and in the same SES quartile – for that criterion. Schools were deemed to be high STEM performing if they exceeded the mean score for their like-school group for all three criteria.

In this chapter, data were also presented about the number of schools meeting one, two or three criteria, identifying that 64 of the 286 schools were categorised as high STEM performing using the school STEM success criteria. Of these, 25 were nonmetropolitan schools, and 19 of these schools were categorised as rural and therefore of interest for the purposes of Phase Two of this study. Finally, the general characteristics of the high STEM performing rural schools were described.
Chapter 6: Case studies of four high STEM performing rural schools

6.1 Preamble
This chapter presents case studies of the four high STEM performing rural schools selected for research through Phase One of this study, identified with the pseudonyms Sweeping Plains College, River Valley College, Alpine Secondary College, and Coastal Secondary College. These schools were deemed to be high STEM performing because they had higher mean achievement levels and enrolment proportions in senior STEM subjects than other non-metropolitan schools with similar socioeconomic status (SES) (see section 4.4.3 for more detail). As described in Section 4.5.1, these four schools are a purposive sample of typical cases (Teddlie & Yu, 2007), representing the variation in school type and SES level of the 19 high STEM performing rural schools identified in Phase One.

Each case study presented in this chapter begins with a brief overview of the context of the school, including its size, student demographics and location. The academic profile of the cohort whose relatively high participation and achievement in senior STEM resulted in the school being included in Phase Two of this project is summarised. This cohort included the students who completed Year 12 in 2014, 2015 and 2016, and thus was the cohort that completed the Year 9 NAPLAN tests in 2011, 2012 and 2013, and also was the cohort that completed the Year 7 NAPLAN tests in 2009, 2010 and 2011. A brief participant profile is offered, including teacher and principal pseudonyms, and the number of student participants and teacher survey respondents. Each case study then describes the practice themes that study participants believed to have contributed to their school’s STEM education success. These practice themes were identified through thematic analysis (Braun & Clarke, 2006) of teacher, student, and principal transcripts, as well as teacher survey responses, and were corroborated through analysis of curriculum documents, timetables and observations made during school visits (see section 4.5.2 and 4.5.3 for more detail). The practice architectures themes, similarly identified through thematic analysis, that enabled these practices at each school are then profiled.

After the individual case studies are presented, the chapter goes on to compare and contrast the manner in which each of the practice and practice architecture themes manifest across the schools. Ten practice themes were identified across the schools, eight of which were manifest in some form in at least three of the four case studies, and only one was unique to a single site. Throughout the discussion of practice themes and practice architecture themes, participant quotes are used to demonstrate what was coded under each theme. These
quotes are illustrative of the interview data collected from across the participants about each theme. Each quote is generally proceeded with the participant’s pseudonym and followed by their role and school, for example “Kevin said, “…” (Principal, Sweeping Plains College)”. This format was chosen to privilege the voice of the participant presenting the view, aligning with Appreciative Inquiry’s approach to valuing the perspectives of all members of an organisation (Reed, 2007). There were ten practice architecture themes identified across the four schools studied, six shared by three or more of the cases, and only two were unique to a single school.

In reading this chapter it is important to note that participant views were collected in various ways, and illustrative quotes are labelled to indicate the data source. Students all participated in group interviews and the source of student quotes are identified with a number and their school – for example “Student 2 Coastal Secondary College” is the second student who contributed to the group interviews at Coastal Secondary College. Quotes from principals are labelled by both their pseudonym and also with their role and school. Teacher data were collected through interviews and through an anonymous survey. Quotes drawn from interviews are labelled both with the teacher pseudonym and the role and school. The source of quotes from the survey are identified with a number and their school – for example “Teacher survey 3 Alpine Secondary College” is the third teacher survey respondent from Alpine Secondary College. It is possible that teacher survey respondents are also those who participated in interviews, however there was no mechanism established to identify if this was the case.

Finally, the terms ‘STEM program’ and ‘STEM team’ are used in this chapter as collective nouns referring respectively to the science, technology and mathematics subjects and activities at the schools, and the teachers who deliver these subjects.

6.2 Sweeping Plains College

Findings from this case study associated with mathematics education have been published in:


(See Appendix A3)
6.2.1 School context
Sweeping Plains College was a co-educational P-12 school with all students located on a single site. In 2016 the school had a population of approximately 136 students, 66 boys and 70 girls, 5% of whom were Indigenous students, and 1% of whom had a language background other than English (ACARA, 2019). These students were supported by the equivalent of 24.3 full-time teachers and 8.6 full-time non-teaching staff (ACARA, 2019). The Index of Community Socio-Educational Advantage (ICSEA) \(^1\) for the school was 963 (ACARA, 2019), indicating the average Sweeping Plains College student came from a relatively low socioeconomic background. Sweeping Plains College served a stable farming community more than 200 kilometres from Melbourne and more than 100 kilometres from the closest regional city. The nearest independent secondary school was approximately 1 hour and 20 minutes’ drive away; however, there were five other government secondary schools within a 30 minute drive. These schools collaborated as part of a network, sharing resources including the Technical Trade Centre built on Sweeping Plains College’s site.

6.2.2 Cohort profile
From 2014-2016, a total of 25 students completed VCE at Sweeping Plains College, with a mean study score of 31.7 across all VCE subjects. Table 31 shows that this cohort’s achievement levels (mean study scores out of 50 for each STEM subject – see section 4.4.3 for further detail) were well above the average of Sweeping Plains College’s like-school group (all non-metropolitan schools in the same socio-economic status quartile – see Section 4.4.3) in all STEM subjects except Biology, where achievement was similar. For example, the mean achievement level in Mathematical Methods at Sweeping Plains College was 30.40 out of 50, compared to the like-schools group mean achievement level of 25.19 for this subject. The enrolment proportions (the mean proportion of enrolments accounted for by each STEM subject – see section 4.4.3 for further detail) were well above average in Mathematical Methods, Specialist Mathematics, Chemistry and Physics, the mathematics and science subjects that serve as prerequisites for entry into many tertiary STEM courses (VTAC, 2016).

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\(^1\) Index of Community Socio-Educational Advantage (ICSEA) is used by the Australian Curriculum, Assessment and Reporting Authority as an indicator of the socio-educational backgrounds of the students at a school. It is calculated using students’ parents’ occupations and education levels, as well as each school’s location and proportion of Indigenous students (ACARA, 2015). It has a standardised national mean of 1000.
as well as in Information Technology. For example, the enrolment proportions for Mathematical Methods at Sweeping Plains College was 7.87%, nearly twice that of the like-schools group with a mean enrolment proportion was 4.18% in this subject. Enrolment proportions at Sweeping Plains College were slightly below the like-schools group mean in Further Mathematics, Biology and Food Technology, and well below average in Psychology. In summary, the 2014-2016 cohort of students at Sweeping Plains College participated in Mathematical Methods, Specialist Mathematics, Chemistry and Physics in higher proportions than students in like-school groups, and they achieved more strongly in all STEM subjects.

Table 31

Mean enrolment proportions and achievement levels from 2014-2016 in Year 12 at Sweeping Plains College and its like-schools group.

<table>
<thead>
<tr>
<th>STEM Subject</th>
<th>Sweeping Plains College</th>
<th>Like-schools group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean enrolment proportion</td>
<td>Mean achievement level</td>
</tr>
<tr>
<td>Further Mathematics</td>
<td>11.02%</td>
<td>31.00</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>7.87%</td>
<td>30.40</td>
</tr>
<tr>
<td>Specialist Mathematics</td>
<td>2.36%</td>
<td>34.00</td>
</tr>
<tr>
<td>Biology</td>
<td>4.72%</td>
<td>27.67</td>
</tr>
<tr>
<td>Chemistry</td>
<td>3.94%</td>
<td>31.80</td>
</tr>
<tr>
<td>Physics</td>
<td>3.94%</td>
<td>33.40</td>
</tr>
<tr>
<td>Psychology</td>
<td>2.36%</td>
<td>39.00</td>
</tr>
<tr>
<td>Information Technology</td>
<td>3.94%</td>
<td>36.60</td>
</tr>
<tr>
<td>Food Technology</td>
<td>3.15%</td>
<td>35.00</td>
</tr>
<tr>
<td>All STEM subjects</td>
<td>43%</td>
<td>32.22</td>
</tr>
</tbody>
</table>

National Assessment Program Literacy and Numeracy (NAPLAN) data show that in Year 7 this cohort’s numeracy results were above state average in Year 7 (571 compared to 551) and in Year 9 (616 compared to 604) (ACARA, 2019). This cohort’s performance in reading in the NAPLAN was also above state average in Year 7 (570 compared to 548.4) and in Year 9 (594 compared to 583.7). It is worth remembering here that Sweeping Plains College was a P-12 college, so it is reasonable to assume that the school’s primary school program had contributed to the relatively strong performance of the Year 7s in NAPLAN testing.
6.2.3 Participant profile

The principal, and six STEM teachers, as identified with pseudonyms in Table 32, participated in interviews at Sweeping Plains College. In addition, five teachers took the opportunity to complete the anonymous online survey. Six female and six male students participated in one group interview.

Table 32

<table>
<thead>
<tr>
<th>Staff member pseudonym</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kevin</td>
<td>Principal</td>
</tr>
<tr>
<td>Karen</td>
<td>Numeracy leader, Teacher (Mathematics)</td>
</tr>
<tr>
<td>Adrian</td>
<td>Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td>Leanne</td>
<td>Teacher (Science)</td>
</tr>
<tr>
<td>Paul</td>
<td>Technology leader, Teacher (Technology)</td>
</tr>
<tr>
<td>Gerty</td>
<td>Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td>Craig</td>
<td>Teacher (Mathematics, Science)</td>
</tr>
</tbody>
</table>

6.2.4 Education practices contributing to Sweeping Plains College’s STEM success

Seven themes emerged from analysis of Sweeping Plains College’s data: high expectations with support; real-world contexts; differentiated instruction; supporting STEM pathways; valuing STEM; careers education; and building STEM teacher capacity. What follows is an exploration of the educational practices captured by these seven themes, illustrated with excerpts from interviews and teacher survey comments.

High expectations with support

The practice of offering extensive learning support to each student, backed by high expectations, was frequently cited as having contributed to the school’s STEM success. Karen said, “The kids know that they can come and ask you anything, or even you get to the classroom they know that we’re there to help too.” (Numeracy leader, Sweeping Plains College). Leanne spoke about supporting students outside class times, “It’s fantastic. The availability of staff as in, I am half-time, but I will come in on my days off or after school and that’s not a problem. I always give them my number.” (Teacher, Sweeping Plains College). Paul talked about providing additional support during school holidays, “I’ll provide any
opportunities, say for instance in this coming term ... holidays I’ll have students come in for extra tuition.” (Technology leader, Sweeping Plains College) The students appreciate the generosity of the staff. One student said, “Teachers will always offer assistance after school and they recommend it sometimes... Certainly, does help you out, that's for sure.” (Student 3, Sweeping Plains College). Another commented, “You get help whenever you want. After school you can go and see them, they're pretty flexible.” (Student 2, Sweeping Plains College).

This generous support was complemented by high expectations for learning in the STEM program. For example, Leanne said, “I always say, ‘We’re a team, we’re trying to get you to get the best results, so we’re a team’, ” (Teacher, Sweeping Plains College). Paul has high expectations in his class, “I like them to achieve... but if something’s not to a good level we say we may need to have another go and repeat it,” (Technology leader, Sweeping Plains College). Gerty said, “I think everyone’s kind of willing to put in that extra, because you kind of get that close relationship with the students, and want to see them thrive more,” (Teacher, Sweeping Plains College). This practice theme of holding high expectations with support was evident in the responses of most of the staff members interviewed and acknowledged by the students, seemingly almost universally believed to have contributed to Sweeping Plains College’s STEM education success.

**Real-world contexts**

There was a focus on explaining how each aspect of mathematics is used in the real-world. Adrian said, “I think as teachers, when we teach maths... we always try to use real-life situations for problem-solving,” (Teacher, Sweeping Plains College). Karen and Craig spoke about explicitly writing on the board why students are learning the mathematics that is the focus of that particular lesson. Various teachers spoke about adjusting their Year 7 to 10 mathematics learning programs to respond to student interest in taxation, finances and farming, noting that students saw the relevance of these real-world contexts and thus were “really engaged and interested,” (Gerty, Teacher, Sweeping Plains College). Adrian spoke about designing units of work based around farming, saying, “Obviously, we always have students in particular in classes that are off farms and if you can connect, make some sort of connection there, that’s always handy,” (Teacher, Sweeping Plains College). The students believed this practice of setting mathematics learning in real-world contexts made the mathematics more relevant and easier to learn. One student said, “She’d relate it back to real life as well so it made it more relatable,” (Student 5, Sweeping Plains College). Another
comment was, “He just related it back to real life, which always makes things a lot easier to remember” (Student 9, Sweeping Plains College). Efforts to seek out real-world contexts in science teaching at Sweeping Plains College seemed less prominent. Leonie spoke about any reference to real-world contexts being guided by the text-book. Similarly, reflecting on his Physics teaching, Adrian said, “In my classes, I teach the VCE subject matter as it is, sort of thing,” (Teacher, Sweeping Plains College). Setting learning in real-world contexts was believed by teachers and students to have contributed to Sweeping Plains College’s success in mathematics, but was not presented as a significant practice, nor contributor to the school’s performance, in science.

**Differentiated instruction**

Sweeping Plains College’s teachers used a variety of strategies to differentiate learning to meet each student’s needs in mathematics. From Year 4 on, the mathematics program involved students taking ownership of their learning through setting learning goals in response to diagnostic testing. These goals were publicly displayed on the classroom wall and students charted their own progress. Karen described this:

> All their learning intentions [are] on a grid for the kids to see. It’s a visual thing with their name on the bottom, [they] colour in what they can do… and their goals are in a light colour... And they just go from one skill to the next as they progress… So today when I wrote on the board, I had I think about nine different things that people were doing in a classroom of… about 20 kids. (Numeracy leader, Sweeping Plains College)

Students also worked in flexible arrangements at the pace and from the stage that suited them for that particular topic. Pre-testing was used for each topic to help students set learning goals and they then accessed their learning program via Google classroom. The teachers made use of online videos, software, activities, games and small group instruction to resource the program and support student learning. Karen said:

> It’s all up on the Google classroom page and the kids just follow through. So on Google classroom page it says watch the clip below, and, if they understand, that they can just go on and do the work. If they don’t understand it, they’ll come and seek support from one of the teachers in the room. Or it might say you need to go and do a focus with the teacher. (Numeracy leader, Sweeping Plains College).
Karen explained the philosophy behind this approach, “They’re building at a very early age that knowledge of, ‘okay there is more to learn and I can’, and building that independence and actually working towards achieving their goals and learning more and more,” (Numeracy leader, Sweeping Plains College).

Several students commented positively about the differentiated mathematics instruction in middle years. One student said, “Splitting them up allows you to continue on with your development while also trying to maybe catch the bottom kids and bring them up… So, it allows everyone to keep developing.” (Student 10, Sweeping Plains College). Another student said, “You wouldn’t have to be doing things with kids that were at a lower level of maths and you would be able to learn the things that you needed.” (Student 9, Sweeping Plains College). Structured differentiation was not evident in the senior years, however students indicated that teachers met student personal learning needs in the upper years of secondary school through extensive out-of-class assistance.

Both students and teachers felt that the differentiated instruction in late primary school and early secondary school was a key contributor to the school’s success in mathematics.

**Supporting STEM pathways**

Sweeping Plains College provided a breadth of STEM pathways. In Years 9 and 10 all students spent one day per week studying vocational oriented subjects in the technical training centre. Many of these subjects were STEM oriented, including Agriculture, Allied Health, Animal Studies, Automotive, Building and Construction, Engineering, Games Design, Kitchen Operations, and Textiles. The school’s technical training programs were seen as improving student engagement with STEM, particularly by highlighting the utility value of STEM. Adrian commented:

> I’ve got a boy in Year 12 now who’s gone through the engineering [course] and so he really loves the idea of being able to apply the mathematics of physics and the maths in the physics in order to calculate formulas for a range of different things. So that is another advantage that we have a bit more access to practical uses of science and technology. (Teacher, Sweeping Plains College)

Participating in Vocational Education and Training (VET) programs also reinforced the importance of mathematics skills. Paul spoke about the role of mathematics in the VET programs: “You’ve got to include numeracy everywhere... Numeracy is paramount. So it’s
imperative that the students, especially in engineering, have numeracy competency.” (Technology leader, Sweeping Plains College). One student spoke about the impact of these VET programs on his choice to pursue a STEM pathway:

I did Engineering. The TAFE’s [Technical and Further Education] just over there and they kind of interrelate pretty well between the VCE and the VET. So, you do both and you can choose your pathway from there and it does help (Student 3, Sweeping Plains College).

In VCE the school provided a diversity of STEM offerings, particularly advanced mathematics and sciences (see Table 31). Despite the school’s small size, this breadth of senior offerings had been normalised. One student said, “I think here they just offer it if there’s interest in that subject... Whereas, I may have been told to go and join a different science or just not do a science at all - so they're very supportive.” (Student 1, Sweeping Plains College).

Students are also supported to accelerate in STEM pathways. In Year 10 many students at Sweeping Plains College accelerate into Year 11 level VCE General Mathematics. This is seen as providing a good opportunity for advanced students, as well as facilitating more effective support for students finding mathematics more difficult. In Year 11, students spoke about accelerating into a range of Year 12 STEM subjects, including Further Mathematics, VET Engineering, and Computer Science Informatics.

Sweeping Plains College’s practice of supporting a diversity of STEM pathways appeared to contribute to student engagement in STEM learning in general.

Valuing STEM
The teachers at Sweeping Plains College invested significant effort into encouraging students and their families to value mathematics and mathematics education. Regular mathematics columns in the school newsletter promoted mathematics activities and the achievement of students. Fortnightly mathematics awards were presented at school assemblies for effort and achievement. Students were supported to participate in a diversity of external mathematics competitions and activities. Every few years Sweeping Plains College hosted a whole school mathematics day. These activities were seen as enhancing the valuing of mathematics by students and parents.

In addition to exploring the real-world applications of mathematics as already discussed, the staff further emphasised the utility value of studying mathematics for accessing
Gerty offered this reflection on this pragmatic approach: “Whatever you do you’re going to need the maths... not necessarily enjoy, but at least persevere with...the majority of them can see that maths is going to be involved in their job, some sort of maths.” (Teacher, Sweeping Plains College).

Practices that enhanced the value of mathematics for students and the wider community were believed to have contributed to student engagement and enrolment in STEM, particularly in mathematics.

**Careers education**
The school ran an extensive careers program beginning in Year 7. Students gathered in year level groups for thirty minutes each week, and a significant proportion of this time was spent exploring careers and future pathways. This program was facilitated by trained staff who managed the career and work placement program across the schools in the local network Sweeping Plains College belongs to. In later years, the careers program included parent information evenings and individual student counselling. Both staff and students spoke about this program contributing to the students’ understanding of pathways and careers, particularly as they related to mathematics. Kevin explained, “That really, I think, supports students when they’re making choices for subjects entering into VCE, there’s great knowledge there and recommendation regarding the need for your maths subjects for example.” (Principal, Sweeping Plains College). Gerty commented that this program led students to understand the importance of STEM in their pathways, “By Year 10 ... the majority of them can see that maths is going to be involved in their job, do some sort of maths, and [many] do at least one science, ’cause they realise that will help.” (Teacher, Sweeping Plains College).

Parallel to this program, staff promoted STEM careers to the wider school community, particularly in mathematics. Karen said, “As a maths KLA [Key Learning Area group] we get sent careers in maths stuff and it’s got examples of how people are using mathematics in their careers so I just publish those on the parent bulletin.” (Numeracy leader, Sweeping Plains College). Careers education and careers related practices were felt to further enhance the value of mathematics at Sweeping Plains College.

**Building STEM teacher capacity**
School leaders invested in building the capacity of STEM teachers through a range of mechanisms. The mathematics staff met every two to three weeks as a numeracy professional learning community (PLC) where they engaged in targeted professional learning activities to
meet school needs. Sometimes the PLC explored particular mathematics content, two examples given being word problems and numeracy fluency, while at other times they considered the mathematics learning needs of particular students. Karen illustrated this, “This is the student I’ve got and this is their background and this is what I’m struggling with… What I want is an idea about what I can do, and things like that.” (Numeracy leader, Sweeping Plains College). The numeracy PLC was also supported to pursue external professional development to help meet the needs of their students, for example having multiple staff trained in the Quicksmart program in response to concerns about the numeracy fluency of their middle school students.

Teachers were also well supported to pursue their own professional learning interests. Kevin said, “We encourage our staff to undertake a lot of PD [professional development], particularly senior teachers, maths teachers, et cetera.” (Principal, Sweeping Plains College). STEM teachers agreed they had good support to attend professional learning, with Gerty noting that this support was far stronger than in her previous school. Several teachers described professional learning they had recently attended, but they also noted the difficulty of time and travel associated with accessing this professional learning. When available, the STEM team engaged with closer professional learning opportunities organised by schools in their network. There was an obligation on those who attend professional development to report back through the numeracy PLC. School leaders had also invested heavily in STEM professional learning as a way to ensure it had STEM staff with appropriate skills, including retraining an art teacher in digital technologies, and a local carpenter as a design technologies teacher. Practices to recruit and develop a strong STEM teaching team were seen by many study participants to have contributed to Sweeping Plains College’s STEM success.

6.2.5 Practice architectures enabling practices contributing to Sweeping Plains College’s STEM success
Participants highlighted a range of interrelated factors that facilitated the practices described in the previous section. These included the school’s rural location, small size, strong relationships, learning culture, local school network, extensive STEM resourcing, and STEM staffing practices. There was also evidence of timetabling and programming arrangements that may also have facilitated practices that contributed to Sweeping Plains College’s STEM success. These enabling practice architectures themes are unpacked in this section and illustrated with excerpts from interviews and teacher comments from the anonymous survey.
**Rural location and small size**

While Sweeping Plains College’s small size and rural location was acknowledged to limit some STEM education practices, it was also seen as facilitating practices contributing to the school’s STEM success. Teachers referred to farming and other local industries as highlighting the utility value of STEM for students. Some teachers also suggested Sweeping Plains College’s isolation and decreasing local employment opportunities were a potential motivator for students to do well in STEM in order to seek study and employment elsewhere.

Both teachers and students felt that the small size of the school and STEM classes, particularly in VCE, made understanding and responding to each student’s learning needs, and maintaining appropriate expectations more achievable. Small classes were seen as providing better access to learning support. A typical student comment about a STEM class was, “it’s pretty small and you get help whenever you want” (Student 5, Sweeping Plains College). At the same time, teachers acknowledged that small class sizes brought challenges, limiting class discussions and activities, diversity of peer support, and student perception of their relative achievement in STEM. Adrian expressed concern that Sweeping Plains College’s students limited exposure to other students resulted in them becoming complacent, saying, “So sometimes they just get in a little bit of a bubble and just roll along.” (Teacher, Sweeping Plains College).

The small size and rural location was seen to facilitate support between staff members and independence. Gerty noted, “If we have questions, [we] can get together ‘cause there’s only a handful of us anyway.” (Teacher, Sweeping Plains College). Adrian said, “From my experience in the country, up here, so much distance from town to town... you’ve got to rely on each other, to get where you want to... That’s what the school does really, really well, I think.” (Teacher, Sweeping Plains College).

The small size and rural location of Sweeping Plains College was generally viewed as an asset, enabling several of the practices felt to have led to Sweeping Plains College’s high STEM performance.

**Strong relationships**

The small size and rural nature of the community was also seen as contributing to building strong relationships between members of the school community, with the small rural community itself presented as a significant enabler of STEM education practices. Participants felt that the strong relationships that exist between staff and students, and between the school and the wider community, both motivated and facilitated STEM education practices. Many
STEM teachers spoke about relationships forged with their students and their families through involvement in sporting clubs and local groups. Adrian explained, “You’ll be seeing teachers down the street all the time, you’ll be perhaps involved in the sporting clubs with them… that does help a little bit with the understanding and the trust and the support.” (Teacher, Sweeping Plains College). Leanne commented, “These are kids of people I know, I’ve had my kids come through, and you just want the best for them. You want them to do the best for themselves. And it matters to me a lot.” (Teacher, Sweeping Plains College). One student reflected:

I think they [teachers] know where you're at and they know what you need help on, and they're willing to follow up… I think in rural areas, they're a bit more personal. Because we're seeing our teachers all the time and not just in school but outside school, like in sporting bodies and other clubs outside of school, so you’ve got a bit more of a personal relationship with them than just that work sort of relationship. (Student 4, Sweeping Plains College).

The strong relationships between all members of the school community at Sweeping Plains College facilitated many of the effective STEM education practices at the school.

**Strong learning culture**

Sweeping Plains College had an explicit culture of high expectations and community connections. One of the school’s values was “Partnerships between the College and the wider community are fostered and valued” (College Profile document, Sweeping Plains College). In addition to values, Sweeping Plains College adopted a set of five pedagogical principles that are featured in its policies and public documents. One pedagogical principle was, “Relationships are the key foundation to developing effective engagement with all members of the community. Interpersonal relationships and collaboration will be fostered within the school community” (College Profile document, Sweeping Plains College). Another was, “High expectations are held for and by the learning community and all members within it” (College Profile document, Sweeping Plains College). Several participants reflected that this culture had contributed to the STEM education practices and success of the school. Kevin said, “I think staff and the school [sic] has high expectations of themselves and that we’re going to get good results and kids sort of know that they’re expected to do well.” (Principal, Sweeping Plains College). A teacher reflected in the survey on factors facilitating the school’s STEM success commented, “The community values education and will support any initiatives put forward by the school. They take interest in the
success of our students.” (Teacher survey 1, Sweeping Plains College). The strong and explicit learning culture of the school was widely attributed with facilitating the school’s STEM success.

Local school network
Sweeping Plains College was part of a long standing collaborative network with six other local schools that was seen to enable many of the practices associated with the school’s STEM success. The most obvious manifestation of this collaboration was the Technical Trade Centre, where the seven cluster schools share technical training facilities that are located on Sweeping Plains College’s grounds. These facilities supported the delivery of a range of STEM related vocational courses, including Agriculture, Allied Health, Animal Studies, Automotive, Building and Construction, Engineering, Games Design, Kitchen Operations, and Textiles that was accessed by students at Sweeping Plains College from Year 9 through to Year 12, with some access by Year 8 students. The network of schools also shared a staff member, who was not based at Sweeping Plains College but who coordinated the school’s careers education and workplace learning programs.

The network schools also supported maintaining the breadth of VCE subject offerings via video conferencing. Kevin said, “It has been very successful, largely because, as a network of schools, we only put in front of the class staff that are strong teachers. And so other students get the benefit of strong teaching there.” (Principal, Sweeping Plains College).

Finally, the network supported building teacher capacity at Sweeping Plains College through informal networking of staff teaching the same subjects, and through sharing formal professional learning opportunities. Several teachers commented on being part of local networks with teachers of the same subjects in neighbouring schools. These networks shared teaching ideas and provide each other advice and support. Leanne said, “There’s a group of local teachers...we try to actually get together, especially when the new study design is coming out and share ideas, so that, I think that’s a really good thing.” (Teacher, Sweeping Plains College). In other instances, schools in the network shared access to external experts running professional learning workshops at their school.

Unconventional timetabling and programming
The timetabling and programming of Sweeping Plains College’s STEM curriculum may have been a further practice architecture enabling the STEM education practices at the school. The
curriculum was delivered conventionally through classes in the separate disciplines of mathematics, science, and technology, similar to in most Australian schools (Marginson et al., 2013). However, mathematics classes were allocated more time than the national average, while science classes were allocated much less. In the primary school, students studied 280 hours of numeracy, and 47 hours of science, each year, compared to an average of 202 hours and 57 hours respectively for Australian Year 4s (Thomson et al., 2017). Students from Year 7 to 9 studied 287 hours of mathematics, and 93 hours of science, whereas the average Australian Year 8 student studies 139 hours and 126 hours per year respectively (Thomson et al., 2017). Interestingly, no participants referred to this difference in time allocation when discussing the STEM success of the school.

In Years 7 and 8, technologies, both design and digital, were offered alongside art as part of a semesterised program, resulting in technologies occupying a proportion of the curriculum similar to that recommended (ACARA, 2012). However, in Year 9 and 10 students spent one day each week in the TTC where they chose from an array of vocational subjects most of which are technology and/or STEM related, arguably raising the proportion of time spent studying technology to 20%, well above the 8% level the Australian Curriculum was designed to deliver (ACARA, 2012).

These unconventional programming arrangements at Sweeping Plains College can be viewed as part of the Practice Architectures that have enabled the school’s STEM education practices.

**Extensive STEM resourcing**

Participants felt that the resourcing of STEM courses and the support for professional learning also enabled many of the practices contributing to the school’s STEM success. In the teacher survey, one teacher commented, “*When asked for support for new equipment or the opportunity to advance teacher knowledge the administration has always provided time.*” (Teacher survey 5, Sweeping Plains College). Another responded, “*Leaders encourage staff to try new things. Willing to finance initiatives.*” (Teacher survey 3, Sweeping Plains College). Yet another teacher said that the school leaders had contributed to the school’s STEM education success, “*By supporting purchase of resources and allowing attendance at relevant PD.*” (Teacher survey 4, Sweeping Plains College). Due to this support, and due to the access to the on-site technical training facility, STEM teachers and students had access to a range of technical resources including 3-D printers, digital lathes, laser cutters, and more.
Several participants at Sweeping Plains College believed that this resourcing enabled some of the effective STEM practices at the school.

**STEM staffing**

Kevin, when discussing the STEM teachers at Sweeping Plains College, commented, “*there’s some strong passionate teachers in those areas… we’re fortunate in that regard.*” (Principal, Sweeping Plains College). The STEM team as a whole was well connected to the school and the local community. Adrian attended as a student, and had spent his career teaching in rural schools in the district. Leonie had her children attend Sweeping Plains College. Karen and Paul were long term staff members and were also strongly involved in local sporting clubs. Sweeping Plains College had faced some staff turnover in STEM - Grace and Craig were new recruits at Sweeping Plains College. Kevin also acknowledged that recruiting STEM staff was challenging. He had employed some creative measures to fill STEM teacher vacancies, including supporting a local tradesman to become a qualified educator, and retraining an Art teacher in digital technologies and coding.

6.2.6 Sweeping Plains College case summary

There were seven practice themes believed to contribute to Sweeping Plains College’s STEM success. Several of these were primarily focused on the mathematics program. There was an emphasis on differentiating mathematics instruction, real-world contexts were used in the mathematics learning program, and efforts to promote STEM predominantly focused on raising the value of mathematics for both students and parents. Further, most of the illustrations offered around the practice themes of careers education and building teacher capacity were mathematics oriented. All the STEM teachers held high expectations of their students, while also providing generous learning support, and the school appeared to make a concerted effort to offer a breadth of senior STEM subjects, including the subjects often serving as prerequisites for tertiary STEM courses, such as advanced mathematics, physics and chemistry (VTAC, 2016).

These practices were enabled by practice architecture arrangements that belong to seven themes. The school’s rural location, small size, and community were viewed, on balance, as an asset to STEM learning. The school also had an established and explicitly recognised culture of learning. The STEM teachers were well connected to the local community and actively promote the school’s learning culture. The school also belonged to a wider network of schools, providing access to teaching and learning resources, as well as
professional learning opportunities. Sweeping Plains College’s extensive Vocational Education and Training programs, complemented by significant high-end STEM resourcing, were also seen as facilitating the school’s STEM performance.

6.3 River Valley College

6.3.1 School Context
River Valley College, located in far north-east Victoria, was a P-12 college built on two sites. Years 5-12 were located on the one site, with Years 5-6 occupying a relatively new flexible learning facility (opened in 2013) and Years 7-12 operating in quite old, traditional buildings. In 2016 the school had a population of approximately 321 students, 153 boys and 168 girls, 1% of whom were Indigenous students, and 1% of whom had a language background other than English (ACARA, 2019). These students were supported by the equivalent of 30.7 full-time teachers and 8.1 full-time non-teaching staff (ACARA, 2019).

The school’s ICSEA was 992 (ACARA, 2019), indicating the SES status of its community is slightly below the national average of 1000 (ACARA, 2015). The college served a relatively isolated rural community, with a population of approximately 2600 people. The significant industries in the area were agriculture, particularly dairy and beef farming, forestry, and hydroelectricity. This community dealt with significant stress due to the vulnerability of these industries to cycles of drought, fire and economic downturn.

River Valley College is located more than 120 kilometers from the nearest regional city, and more than 440 kilometers from Melbourne. The nearest secondary college was approximately 1 hour by car. The nearest independent secondary school was approximately 1.5 hours by car. There was a bus service to this independent school; however that was discontinued at the end of 2017.

6.3.2 Cohort Profile
The mean enrolment proportions and achievement levels in Year 12 from 2014-2016 at River Valley College compared to its like-schools group are shown in Table 33. The STEM enrolment proportion for River Valley College at Year 11 level was 48% and at Year 12 level was 46%, above the average STEM enrolment proportions of its like-schools group of 44% and 44% respectively. Of note, River Valley College enrolment proportions in Mathematical Methods, the more advanced mathematics, was nearly twice that of the mean of the like-
schools group, while River Valley College enrolment proportions in Further Mathematics, an entry level mathematics, was nearly half that of the mean of the like-schools group. River Valley College students achieved an average study score in STEM of 29.79, well above the like-schools group average of 27.38.

In Year 7 the study cohort at River Valley College scored an average reading result of 535 and an average numeracy result of 556 in NAPLAN reading and numeracy testing, compared to the Victorian averages of 548.4 and 551.2 for these tests respectively (ACARA, 2019). This suggests that this cohort of students at River Valley College commenced their secondary schooling with poorer reading skills than average Victorian students and numeracy skills similar to those of the average Victorian student. When in Year 9 this cohort scored an average reading result of 593 and an average numeracy result of 604.3, above the Victorian averages were 583.7 and 589.7 for these tests respectively.

Table 33

<table>
<thead>
<tr>
<th>STEM Subject</th>
<th>River Valley College</th>
<th>Like-school group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean enrolment</td>
<td>Mean achievement</td>
</tr>
<tr>
<td></td>
<td>proportion</td>
<td>level</td>
</tr>
<tr>
<td>Further Mathematics</td>
<td>7.07%</td>
<td>27.68</td>
</tr>
<tr>
<td>Mathematical Methods</td>
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<td>Biology</td>
<td>9.00%</td>
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<td>Chemistry</td>
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<td>30.50</td>
</tr>
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<td>Physics</td>
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</tr>
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<td>Psychology</td>
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<td>33.91</td>
</tr>
<tr>
<td>Design &amp; Technology</td>
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<td>29.47</td>
</tr>
<tr>
<td>All STEM subjects</td>
<td>46%</td>
<td>29.79</td>
</tr>
</tbody>
</table>

6.3.3 Participant profile

The principal, and nine STEM teachers, as identified by their pseudonyms in Table 34, participated in interviews at River Valley College. In addition, seven teachers took the opportunity to complete the anonymous online survey. Three female and three male students participated in a single student group interview.
6.3.4 Education practices contributing to River Valley College’s STEM success

Nine practice themes related to the school’s STEM success emerged from analysis of River Valley College’s data: High expectations with support; hands-on activities; real-world contexts; place-based learning; differentiated instruction; supporting STEM pathways; valuing STEM; careers education; building STEM capacity. What follows is an exploration of the educational practices captured by these nine themes, illustrated with excerpts from interviews and teacher survey comments.

**High expectations with support**

Strong support and high expectations for all learners were seen as contributing significantly to the school’s STEM success. Students described the impact of this approach by their STEM teachers. One student said, “They check on us… They’re making sure that we’re staying up on level and keeping on track. It’s good to know that they’re watching out for you” (Student 5, River Valley College). Another student said, “They want you to do as good as you can as well” (Student 6, River Valley College). Another student commented:

Teachers are engaging and they’re supportive of you. They push. They want you to do your best and if you … show some proliferation [sic] in science or maths or whatever, they’ll definitely push you to excel in those if they think you can go for it (Student 2, River Valley College).

This supportive approach backed by high expectations was evident for all students and across the year levels. A concrete example of the extensive support offered to students by the STEM team were the afterschool help sessions that were attended by students from Years 5 to 12. One student said, “I think everyone’s aware that not many schools get that sort of
treatment, like that’s every class, especially in the sciences that we get the opportunity that’s, like, everyone’s free to go to that and, yeah I’m sure that makes a hell of a difference to our results. And that’s done from a young age too.” (Student 2, River Valley College). Teachers also offered out-of-hours help outside these scheduled sessions. One student said, “So, I know with my psychology, my maths and my bio teacher, and my chem teacher - actually they all do after school classes if you need help.” (Student 5, River Valley College). The STEM teachers offered support in other ways, including sharing their phone numbers and establishing Facebook groups to offer senior students out-of-hours support. Structurally, high achievers at the school were supported in STEM by Year 10 and 11 students being allowed to accelerate into higher levels of mathematics and science.

Teachers and students alike felt that the combination of high expectations for learning and improvement, alongside generous STEM teacher support, was a key practice that contributed to River Valley College’s STEM performance.

**Hands-on activities, real-world contexts, and place-based learning**

There was a strong emphasis at River Valley College on providing hands-on learning tasks and tasks set in the local context, in STEM classes. Veronica felt the rationale for this approach was obvious, asking, “How else do you get kids to be enthusiastic about something unless you make it a bit fun and are creative and put it into their real day context?” (Mathematics leader, River Valley College).

Teachers variously viewed hands-on activities as ways to make abstract learning concrete, to engage students through fun, and to give learning real meaning to their students. Mathematics teachers spoke about using kits of puzzles, concrete materials and double-sided rulers to assist students with problem solving. They spoke about building spaghetti bridges, constructing and racing cars, launching rockets, Barbie bungee jumping, and a range of other activities that different teachers said “get[s] them interested”, “sucks them in”, and were “cool” and “fun”.

The students valued the hands-on nature of the STEM program. One student commented on experiences in Year 9 saying, “If you asked me to remember something that… was just taught on the board, like, and that didn’t happen all that often, like but I couldn’t remember it. But ask me what we did in a prac and I could remember it straight away,” (Student 3, River Valley College). Another student offered this reflection on learning in senior school, “He always has something. Like, he had brought in an alternator or a bunch of
copper tubing or whatever else and... actually shows us what these concepts are.” (Student 2, River Valley College).

Much of the STEM learning at River Valley College could be characterised as place-based, being active learning located in real-world contexts that the students are familiar with, namely their school, the local environment and local industries. Teachers spoke about using local issues such as river fishing, dung beetles, and water fluoridation as contexts for their lessons. A universal issue like waste was explored in the context of the school and local community. Stuart said, “The kids are really involved with looking at the waste problem at the school and making some changes” and “they’ll come in and they’ll talk about the fact that when they drove to school they noticed all this rubbish down the side,” (Science leader, River Valley College). In Mathematics, the Year 8s hatched and raised chickens, eventually taking some of the chickens to a local agricultural show. Year 5/6 students designed and built wombat traps as part of a unit that included exploring the work of Leonardo Da Vinci. Like many Victorian schools, River Valley College operated a Stephanie Alexander Kitchen Garden\textsuperscript{2} program (Stephanie Alexander Kitchen Garden Foundation, 2019), however the garden had become a site for a range of other activities. Veronica said, “We went and tested how many earthworm species there are in the veggie patch. [Laughing]. There’s four,” (Mathematics leader, River Valley College). Students of different year levels had also been involved in construction projects and extended investigations centred on the garden. “When we’d do an environmental ag [sic] kind of project we were using the Stephanie Alexander garden, like to grow crops with light, without light, fertiliser, chicken health,” Veronica (Mathematics leader, River Valley College) said. Cows Create Careers\textsuperscript{3} (Dairy Australia, 2019) was another popular program at the college, with the school housing a group of calves borrowed from a local farmer on the property.

Place-based learning engages students in learning activities with an authentic purpose. Many of the place-based STEM learning activities at River Valley College involved students in projects that made a contribution to the school community. Students planned and ran STEM activities for other students. Stuart described one example where students chose a project involving “making bees wax paper or, you know, doing workshops with other kids in other units, other year levels to make their own bees wax paper so they can wrap their

\footnote{2} The Stephanie Alexander Kitchen Garden program involves students in the growing and cooking of fruit, vegetables and herbs. See https://www.kitchengardenfoundation.org.au/

\footnote{3} The Cows Create Careers program involves students in raising and caring for cattle. See https://www.dairyaustralia.com.au/farm/people/dairy-education-and-careers
lunches up in that,” (Science leader, River Valley College). Junior students were often used as an audience to share STEM learning with. Janet said:

Often if the students up here have done experimentation and it’s gone well and they get really excited, well, then the science teachers will say to them, ‘Okay let’s, let’s go down and see what you can teach the little ones’ (Principal, River Valley College).

Students from Years 5 to 7 took responsibility for running STEM days. Janet described these days:

The STEM days that are set up are huge… Kids will organise all the events and the activities and, you know, the problem solving around it … We say to them, ‘Okay you’re going to develop something but how are you going to make this work if a prep/1 student comes? How are you going to make it work if a Year 9/10 student comes?’ (Principal, River Valley College).

Hands-on activities, real-world contexts and place-based learning practices were ubiquitous in STEM learning from Years 5/6 through to Year 12 at the school. Collectively, they were felt to engage, motivate and challenge students.

**Differentiated instruction**

Personalised learning was seen as a significant contributor to River Valley College’s STEM success. Janet said, “We do know our kids back to front. We know exactly who they’re related to. We know their interests. We know their triggers. We know their mood swings, their, you know, we know everything about them,” (Principal, River Valley College). This intimate knowledge of each student was seen as supporting differentiated instruction on a case-by-case basis. Teachers spoke about adjusting learning programs to meet the learning needs of individual students, either to provide extra support, or to extend their learning. Veronica spoke about supporting and encouraging individual learners, “I say, ‘You’re starting here and we’re achieving and getting better. Everyone has to get better and … everyone starts at different places.’” (Mathematics leader, River Valley College). One student spoke about the impact of being supported to extend his mathematics learning, saying:

Since I was young I sort of had a little bit of interest but my teacher now I’ve really got an interest in it because instead of holding me back with the level that we’re at, she’s letting me go forward
In Years 5 and 6, differentiated instruction in STEM was highly structured. Students had full access to the learning program, more recently through Google Classrooms and, prior to that, through hardcopies kept in student accessible folders, and were able to move through materials at their own pace. Further, they were expected to manage and monitor their own progress by setting their own goals and recording their own learning data in a spreadsheet. Stuart said, “It’s the kids’ data. They need to own it, sort of thing. Same with learning goals.” (Science leader, River Valley College).

**Supporting STEM pathways**

Students at River Valley College were supported to pursue STEM pathways through a range of mechanisms. Significant choice was built into the curriculum structure, with Science and Technology offered as part of the elective program in Years 9 and 10. However, the students expressed mixed feelings about these electives with some saying they enjoyed the electives, and others suggesting some were a “bludge” and expressing annoyance about this. More positively viewed by the students was the opportunity to accelerate into some senior STEM subjects in these elective blocks, such as Chemistry, Engineering (Certificate II), and Psychology. One student spoke about choosing to accelerate into Chemistry, “I did year 11 chem in year 10 and then I did year 12 last year… I enjoyed it and [the school] supports when you’re doing it… they believe you can you do it,” (Student 2, River Valley College).

Real efforts were made to maintain a good breadth of offerings in VCE STEM at River Valley College. The timetable had been adjusted in order to recruit a Mathematical Methods teacher to ensure they could offer advanced mathematics. Chemistry and Physics ran, despite very low numbers, sometimes as composite classes if numbers are particularly low, to maintain these science pathways.

**Valuing STEM**

Various practices that promote the value of STEM to the students and the wider community were employed at the school. STEM activities were run at lunchtimes, allowing participation or viewing by students across the school. The STEM team also hosted evenings featuring a variety of STEM activities that the teachers indicate were very well attended by students and their parents, “40, 50 people come along to those sort of nights.” Stuart said, “So over the
years ... we’ve done lots of hands on activities and evening activities to get them interested.” (Science leader, River Valley College). There were other highly visible practices that reinforced the profile of STEM at the school, including keeping livestock and showing livestock at local Agricultural shows, building and maintaining the Stephanie Alexander gardens, STEM camps to Canberra, a mechanics program run out of the Community Neighbourhood Centre, and training programs with the local emergency services.

**Careers education**

The school’s career education practices were also seen as contributing to River Valley College’s STEM success. The careers program commenced at Year 8, with students engaged in learning about career pathways. It included parent information sessions and individual counselling to help students who are making subject choices and decisions about their future. STEM teachers and students both referred to the impact of this program. Meredith commented, “I think the career program is really good... There’s individual counselling for each child. ... It’s huge but it’s so well worth it.” (Teacher, River Valley College). The students also recognise the role the career program plays. Responding to a question about why students chose STEM subjects at River Valley College students said, “Quite early we get the career advisory. So you get an idea of what you want to do and ... what electives you have to choose for VCE,” (Student 1, River Valley College). Another student said, “So they really push you for something that you enjoy doing... they’re not about making you do something you don’t like,” (Student 5, River Valley College). One student felt that these efforts resulted in all students having concrete aspirations, commenting, “Everyone’s got a plan even if they’re going to an apprenticeship or something. It doesn’t require them to be necessarily STEM, like going into high STEM sort of things,” (Student 2, River Valley College).

The careers program was enriched through incursions and excursions with local businesses, which often operate in STEM related industries. Janet described the importance of these activities:

The kids actually need to see well what is out there for job aspirations… We’ve been trying to invite people in constantly. So, [local water authority] come in and they work with the kids [and] they go out and have field days … We’ve had… three excursions going to the [local hydroelectric facility] … The kids find it really interesting but it also broadens their horizon about what they can do (Principal, River Valley College).

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**Building STEM teacher capacity**

The STEM team adopted a collaborative approach to building teacher capacity, with each member viewed as a learner with strengths and areas where they can learn more. The STEM teachers saw there was real expertise across the STEM staff. The STEM teachers described different STEM colleagues in interview as “very strongly hands on”, “good at differentiating”, “very intelligent”, “lead[ing] really, really well”, and “well-prepared and well qualified”. Further, the STEM teachers believed that all staff members are on a learning journey, constantly seeking to improve their practice. The STEM team employed a wide variety of practices to further their development as teachers, including accessing online courses, reading educational research, and consulting with local groups such as Landcare and Water-watch. Experienced STEM teachers mentored teachers new to senior classes. Similarly, those with strong pedagogical knowledge in the junior area offered support to those more familiar to senior teaching. For example, Veronica spoke about helping another STEM teacher, “We’ve had a couple of conversations about how you teach the simpler stuff because I was, I’ve always kind of stuck seven eight [taught in Years 7 and 8], I got into the primary school to teach, experience them,” (Mathematics leader, River Valley College).

Learning was shared amongst the STEM staff, with staff sharing any PD workshops or online learning they participate in with colleagues. Secondary school teachers supported numeracy intervention and science programs in the primary school. Janet summed up the collaborative approach to staff development, “There’s strengths in everyone and weaknesses in everyone, but I think that’s also the really strong thing about our collegiality” (Principal, River Valley College). The practice of shared and ongoing professional learning was felt to be an important contributor to River Valley College’s STEM performance.

**6.3.5 Practice architectures enabling practices contributing to River Valley College’s STEM success**

There were a range interrelated practice architectures that appeared to enable the practices believed to contribute to River Valley College’s STEM success, including its rural location, small size, strong relationships and strong learning culture. Also, some unconventional approaches to timetabling and programming the STEM curriculum have been used at the school, and school leaders have worked hard to make best use of the staffing opportunities they had. These enabling practice architectures themes are unpacked in this section and illustrated with excerpts from interviews and teacher comments from the anonymous survey.
Rural location

River Valley College’s rural location was felt to shape the STEM education practices of River Valley College in several ways. First, it was felt to positively predispose the school community and wider community towards STEM. In the STEM teacher questionnaire a teacher linked the agricultural location to the community having a “positive attitude towards STEM and its necessity,” (Teacher survey 2, River Valley College). Another teacher wrote “We have farmers [and hydroelectricity] workers who believe STEM is important for their child’s education,” (Teacher survey 5, River Valley College). Students felt that the school strongly valued STEM, with one student commenting, “We’re quite a strong science based school... We’re in an ag [agriculture] community and science is probably something that most of us probably look at in the next level of Uni [university],” (Student 5, River Valley College). The rural location also provided the school access to resources and local contexts that supported their STEM education programs. One teacher commented in the teacher questionnaire about the, “great local resources.” (Teacher survey 1, River Valley College). Teachers spoke about using local issues such as river fishing, dung beetles, and water fluoridation as contexts for their lessons. Extended programs, like the Cows Create Careers, were dependent on the school having the room and rural network for their success. Less extensive learning programs similarly exploited the rural context. Year 9s were able to investigate putrefaction by setting up their own ‘body farm’ using chunks of meat kept in various conditions. Veronica suggested the biggest obstacle to such a potentially confronting exercise was how to fox proof the samples, and even this was seized as an opportunity to investigate engineering solutions to keep the samples safe.

The rural location was seen as a mixed blessing when it came to staffing STEM subjects at the school. Several participants noted recent difficulties recruiting mathematics and technology teachers. However, once staff members became established in the rural community they seemed to commit long term to the school. Four of the STEM teachers had been at the school for more than 15 years, had had children of their own attend the school, and occupied significant STEM leadership positions at the school. Liz said, “A lot of us are really invested in the school. That’s why we run things” (Numeracy leader, River Valley College).

Participants acknowledged that their isolated rural location also constrained their practice, limiting their access to excursion destinations, visiting experts, professional development, and qualified staff. However, participants’ reflections suggested that this had
prompted a culture of self-reliance and creativity amongst the STEM teachers. Stuart commented:

So there’s a lot of things that we do miss out on but in one respect that’s made us more independent. Instead of waiting for someone to come to us and do something, we would actually go out and seek information on the web and then we’d say, ‘Okay let’s do that.’ (Science leader, River Valley College)

A respondent to the teacher survey wrote, “We are a rural school that is quite isolated so we have had to become quite creative … We have discussed attending offsite PD but think that we can collaborate and do our own research better” (Teacher survey 5, River Valley College). School leaders were seen as encouraging of this culture, with teachers saying leaders supported staff to “try new things” and “do activities out of the box.” Ultimately this seemed to have resulted in the River Valley College STEM team understanding themselves as people willing to take risks and try new things. Veronica said, “We do a lot of things that we’re the first in the area.” (Mathematics leader, River Valley College). Stuart offered this tongue-in-cheek comment, “Not many people actually come up and check to see what we’re doing, so if we’re doing something wrong, you know, they never know about it” (Science leader, River Valley College).

Small size and strong relationships

Participants at River Valley College felt that the strong relationships between all members of the community facilitated STEM education practices at the school, and that these relationships were enabled, in part, by the small school size. One student commented “I reckon our best asset is that we’re small and that we can have teachers focus on the students easier but you can’t do that in bigger schools.” (Student 5, River Valley College). In the group interview, Joan offered, “I also think, like you’re in a small community here so you not only know them but you know their family … their older brothers and sisters.” (Teacher, River Valley College). The small teaching team meant that teachers worked with the same students throughout their schooling, building their relationship and their understanding. Simon said, “I think it’s great teaching the lower kids and then catching them up when they get to Year 11 and 12 because you’ve got, they know you, like, it sort of breaks a lot of barriers.”(Teacher, River Valley College). The STEM team worked together to build student-teacher relationships. Veronica said in the group interview, “We talk to each other a lot
about… what’s …happening with this child or why, why they’re having troubles. So I think we do communicate…. So we know what’s going on with their life and what their problems are.” (Mathematics leader, River Valley College). The strong relationships were believed to motivate STEM teachers to work hard for the students. Veronica spoke about being motivated by a desire to do the best for each of her students, “I just feel like I have to help them to get where they want to go. Like, what if they didn’t go well and they were stuck in [town name] … I will see them in 20 years’ time, unhappy” (Mathematics leader, River Valley College).

**Strong learning culture**

The school, and the STEM team in particular, developed and maintained a safe and encouraging learning environment. In the survey a STEM teacher commented, “The school provides a safe and encouraging learning environment for students… which values motivation, aspiration and achievement.” (Teacher survey 2, River Valley College). STEM teachers spoke about being attentive to the backgrounds and emotional needs of their students. STEM teachers took financial constraints and workloads at home into consideration. Liz justified some of her chosen practices in terms of the emotional impact on students. She described mathematics as “the worst subject as far as damaging kids. It’s really bad” (Numeracy leader, River Valley College). She also expressed frustration about how students encountering difficulties in mathematics are described. “We call them weaker students in mathematics. Where did that come from? Weaker? That’s such a put down” (Numeracy leader, River Valley College). Beyond striving for a safe learning environment, there appeared to be a pervasive culture of encouragement and aspiration. Janet credited this culture with facilitating much of the school’s STEM success, “I really think that it’s got a lot to do with our culture to be honest and our celebration of all achievement” (Principal, River Valley College). One student said, “They want you to do as you can as well. And, yeah I think all the kids want to do well. Like it’s, yeah, seen as desirable to do well at school here, so that’s pretty important I think.” (Student 6, River Valley College). Another student commented:

The actual level of enthusiasm and commitment and how much these teachers care here, not even in the higher years, in the lower years as well, how much they actually care about the students and how well they do is awesome… It is one of the reasons why everyone is always doing harder subjects and always pushing themselves because they have teachers there that care and are putting
in a lot of time and effort for it. They’re very enthusiastic about it. (Student 2, River Valley College).

The learning culture of River Valley College was explicit school wide, but particularly prominent in the STEM subjects, contributing to the success of the school’s STEM education practices.

**Unconventional timetabling and programming**

The STEM curriculum at River Valley College was delivered as an integrated subject in Years 5/6, but reverted to traditional discipline based subjects at the beginning of secondary school. Students in Years 7/8 studied Mathematics for approximately 167 hours, and Science for 100 hours, respectively well above and well below the national averages of 139 hours and 126 hours per year for this subjects (Thomson et al., 2017), however participants did not draw attention to this as enabling or constraining any STEM education practices. Students in Year 9/10 continued to study mathematics as a compulsory study throughout the year, with both year 9 and 10 mathematics classes scheduled at the same time. Science and technology were offered as semester long elective units available to both year 9 and 10 students. This elective structure was not mentioned as contributing significantly to the school’s STEM success, with some elective subjects being remembered by students as fun but unproductive. More positively viewed was the opportunity to accelerate into some senior STEM subjects in these elective blocks, such as Chemistry, Engineering (Certificate II), and Psychology.

**STEM staffing**

River Valley College had a mix of experienced and inexperienced STEM teachers. Several of the STEM teachers had been at the school for many years, and had had their own children attend the school. Others were new to the school and the district. Janet described the STEM teachers as a good team who worked together well making good use of their complementary strengths and weaknesses. The school had had recent difficulties recruiting mathematics and technology teachers. School leaders had adopted some creative strategies to overcome recruitment and retention difficulties. Flexible work arrangements were offered to teachers, and local networks were used to find employment for the teachers’ partners. For example, the school timetable had been built around the work hours of the local café owner to secure his services as a qualified Mathematical Methods teacher. This strategy was viewed positively by staff and students alike.
6.3.6 River Valley College case summary

There were nine practice themes believed to contribute to River Valley College’s STEM success. There was significant use of hands-one activities, real-world learning contexts, and place-based learning opportunities in both mathematics and science across year levels. STEM teachers held high expectations for student learning and gave generous help to support student learning, including personalising learning to meet the needs and interests of each student. Activities that contribute to the value attached to STEM learning were promoted at the school, and a variety of STEM learning pathways were supported, including by facilitating acceleration in STEM subjects and ensuring a breadth of VCE STEM subject offerings. Finally, there was a dedicated team of STEM teachers who worked to support each other to develop as STEM teachers.

These practices were enabled by practice architecture arrangements that belong to six themes. The school’s rural location and small size were viewed as an asset for personalising and enriching STEM learning. Strong relationships between all members of the school community, along with an explicit school learning culture that aims for and celebrates improvements, were seen as significant enabling factors. Also acknowledged as facilitating success was the school’s integrated STEM course in Years 5 and 6, and the school’s creative efforts to recruit and develop an effective team of STEM teachers.

6.4 Alpine Secondary College

Findings from this case study associated with science education have been published in:


6.4.1 School Context

Alpine Secondary College, located in the alpine region of north-east Victoria, served families who lived in and around the surrounding national and state parks, and agricultural properties. In 2016 the school had a population of approximately 170 Year 7 to 12 students, 81 boys and 89 girls, 2% of whom were Indigenous students, and 8% of whom had a language background other than English (ACARA, 2019). These students were supported by the
equivalent of 19.7 full-time teachers and 3.4 full-time non-teaching staff (ACARA, 2019). The school had relatively old but well-presented buildings, with traditional science, manual technology, textiles, and computing facilities.

In 2016, the school’s ICSEA was 1023 (ACARA, 2019), indicating the SES of its community is slightly above to the national average of 1000 (ACARA, 2015). The school was approximately 355 kilometers from Melbourne, and 86 kilometers from the nearest rural city. The major industries in the district included agriculture, forestry, construction, and accommodation and food services. The nearest government secondary college was approximately 30 minutes away by car, with the nearest independent schools more than 50 minutes away.

6.4.2 Cohort Profile

From 2014 to 2016, 66 students completed VCE at Alpine Secondary College. The STEM enrolment proportion for Alpine Secondary College at Year 11 level during the study period was 47% and at Year 12 level was 42%, above the average STEM enrolment proportions of its like-schools group means of 43% and 41% respectively (see Table 35). Particularly noteworthy, the enrolment proportions were well above average in Mathematical Methods, Specialist Mathematics, Chemistry and Physics -- the mathematics and science subjects that serve as prerequisites for entry into many tertiary STEM courses (VTAC, 2016) -- as well as in computing subjects. Alpine Secondary College students achieved an average study score in STEM of 28.23, whereas its like-schools group average STEM study score was 27.84.

In Year 7 the study cohort at Alpine Secondary College scored an average NAPLAN reading result of 567 and an average numeracy result of 557, above the Victorian averages of 548 and 551 for these tests respectively (ACARA, 2019). When in Year 9 this cohort scored an average reading result of 589 and an average numeracy result of 598, showing greater gain in numeracy than reading and remaining above the Victorian averages of 584 and 590 for reading and numeracy respectively.
Table 35

Mean enrolment proportions and achievement levels from 2014-2016 in Year 12 at Alpine Secondary College and in its like-schools group

<table>
<thead>
<tr>
<th>STEM Subject</th>
<th>Alpine Secondary College</th>
<th>Like-schools group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean enrolment proportion</td>
<td>Mean achievement level</td>
</tr>
<tr>
<td>Further Mathematics</td>
<td>10.58%</td>
<td>27.18</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>6.35%</td>
<td>26.46</td>
</tr>
<tr>
<td>Specialist Mathematics</td>
<td>1.32%</td>
<td>23.40</td>
</tr>
<tr>
<td>Biology</td>
<td>6.08%</td>
<td>27.50</td>
</tr>
<tr>
<td>Chemistry</td>
<td>5.03%</td>
<td>31.11</td>
</tr>
<tr>
<td>Physics</td>
<td>6.08%</td>
<td>27.74</td>
</tr>
<tr>
<td>Psychology</td>
<td>1.59%</td>
<td>30.67</td>
</tr>
<tr>
<td>Food Technology</td>
<td>1.59%</td>
<td>31.50</td>
</tr>
<tr>
<td>Computing: Informatics</td>
<td>3.17%</td>
<td>32.55</td>
</tr>
<tr>
<td>Computing: Software</td>
<td>2.65%</td>
<td>27.50</td>
</tr>
<tr>
<td>development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All STEM subjects</td>
<td>42%</td>
<td>28.23</td>
</tr>
</tbody>
</table>

6.4.3 Participant profile

The principal, and seven STEM teachers, as identified by their pseudonyms in Table 36, participated in interviews at Alpine Secondary College. In addition, seven teachers took the opportunity to complete the anonymous online survey. Six female and five male students participated in one of two student group interviews.

Table 36

Alpine Secondary College staff interview participants and roles

<table>
<thead>
<tr>
<th>Staff member pseudonym</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sally</td>
<td>Principal</td>
</tr>
<tr>
<td>Jirra</td>
<td>Mathematics &amp; Science leader, Teacher (Mathematics, Science)</td>
</tr>
<tr>
<td>Craig</td>
<td>Teacher (Mathematics &amp; Science)</td>
</tr>
<tr>
<td>Tracy</td>
<td>Laboratory manager</td>
</tr>
<tr>
<td>STEM teacher group interview (Peter, Nancy, Britta, Yvonne, Jirra)</td>
<td>5 teachers of Mathematics, Science &amp; Technology</td>
</tr>
</tbody>
</table>
6.4.4 Education practices contributing to Alpine Secondary College’s STEM success

Eight themes related to the school’s STEM success emerged from analysis of Alpine Secondary College’s data: high expectations with support; hands-on activities; real-world contexts; place-based learning; supporting STEM pathways; skills focus; valuing STEM; and building STEM teacher capacity. What follows is an exploration of the educational practices captured by these eight themes, illustrated with excerpts from interviews and teacher survey comments.

**High expectations with support**

Alpine Secondary College students were set high and realistic learning expectations in STEM. One student said of their STEM teachers, “They expect you to do your best.” (Student 7, Alpine Secondary College). Another student felt expectations were tailored to their abilities, saying:

> They don't expect so much that they make it an impossible thing to achieve those goals… they'll assist you in different things, but not to the point where they're doing it for you. Just enough to get you to where you need to be. (Student 11, Alpine Secondary College)

Another student commented, “The expectations for different people is different, I guess, but they just expect that you will go to where they expect that you will.” (Student 8, Alpine Secondary College). Jirra offered this view on the expectations set by the STEM team:

> Achievement doesn’t necessarily mean attaining a perfect score, achievement in our school is always pushing a kid to go ‘did you do better than last time?’… [It] doesn’t matter where you start, it matters that you grew from where you were to where you are now. I think we’re very good at doing that…Any kid can walk into a mathematics or science class and feel like they can achieve because we know how to make the goal posts appropriate to them. (Mathematics and Science leader, Alpine Secondary College)

STEM teachers backed the high expectations by offering generous support to their students. A student commented, “The STEM teachers are pretty outstanding with their effort that they want to put in, and the outside of class time is really, really good” (Student 1, Alpine Secondary College). Another said, “They're all really willing to drop what they're doing and
help if you ask for it. Which is something that's really, it's quite unique.” (Student 4, Alpine Secondary College). A teacher wrote in the survey, “Teachers are generally very dedicated to their students and go out of their way to provide them with the help they need.” (Teacher survey 2, Alpine Secondary College). Britta commented in the group interview, “Wherever their level is, they know that they can get help and assistance, and they know that a teacher is always there” (Teacher, Alpine Secondary College).

**Hands-on activities**

Participants felt that an emphasis on fun and active STEM learning had contributed to the school’s relative STEM success. Several staff suggested this focus was driven by the previous principal. Sally said that the previous principal “firmly believed that engaging kids with prac [practical activities] will build a love [and] thirst for those subjects.” (Principal, Alpine Secondary College). The students affirmed the effectiveness of this approach. One said, “We do a lot of interactive stuff, like dissections and practicals that make the class work interesting” (Student 7, Alpine Secondary College). Another noted, “they make subjects fun... having fun classes that they're like, well science is actually fun. 'Cause it can sound really boring, and hard, but it's actually not” (Student 4, Alpine Secondary College). Craig described the value of nurturing a fun in the STEM classroom:

NO-ONE [interviewee emphasis] can learn if they’re scared, whatever it is, people aren’t going to learn anything if they’re scared, and they’ll learn even better if they’re happy, if they’re enjoying what they do, and you cannot trick them into working but you make it fun so they want to work… I think you’ve got to have engagement before you can do anything else. Otherwise you’re just flogging a dead horse, really. (Craig, Teacher, Alpine Secondary College).

This emphasis on engaging students in STEM learning began from the very beginning of secondary school. One student commented, “I think it starts from Year 7 and Year 8 here, they really ignite the passion in kids at a young age. Which I feel like they don't at some big schools in other places.” (Student 3, Alpine Secondary College). Another expressed similar sentiments: “I guess, like, it was helpful in the younger years that ... they were interesting and really interactive. And it kind of got students hooked on the subject, so then they all wanted to pursue it more.” (Student 7, Alpine Secondary College). Even during transition sessions with the local Year 5 and 6 students, this aspect of STEM education at Alpine Secondary College was showcased. Jirra said, “Anything that goes ‘bang’, or goes 'ew’ they’re good for! I’ve done water canister rockets... flame tests. We made rainbow cylinders,
Real-world contexts and place-based learning

The STEM team also located student learning in real-world and local contexts as a way to engage students. Craig said that it was important to “make them think it’s a fun thing and try and relate it to real life situations, if you can” (Teacher, Alpine Secondary College). Science teachers at Alpine Secondary College had as one of their three stated objectives “to make all students aware of the environmental issues of science... the impact of science and technology on society [and] emerging knowledge, issues and scientific debate” (Student course handbook, Alpine Secondary College). The science elective units were dominated by the exploration of real-world applications of science, including climate science, medicine, agriculture, criminal investigation, and alternative energy. The mathematics course descriptions also explicitly mentioned real-world contexts, such as rainwater collection, trigonometry in sports, real-world applications of geometric shapes, and statistical investigations.

The STEM team also made good use of the local area to provide students relevant and real-world learning opportunities. They worked with a range of local organisations including a hydro-electricity supplier, an alpine resort, the water supplier, the airport, the sewerage farm, and the local dairy industry. Craig explained how he used the local resources to enhance learning for his students:

We have a lot of connections around here… I’ve got a fellow, who’s the partner of a teacher who works at the school, we’re doing particle accelerators, and he worked on one, in South Africa. So I got him in and he just spoke for half an hour to the Year 12 kids, about his experience working with the particle accelerator, which was pretty awesome. You don’t meet people that have done that every day. I really think it’s useful to get whatever use, whatever resources you can. We’ve got an airport over the road, when we were doing aerodynamics we’d take them over and get the local pilot to pull out a glider and show us what the control surfaces do, and get them all in there. It’s great. Same guy actually has a house that’s off the grid, totally, it runs on solar. So just to get him explaining the whole system and how he feeds back into the grid and all that. When we’re doing that it’s gold. You see it just sinking into the kids. “Actually you’re not just speaking crap, you’re actually”... yeah! (Craig, Teacher, Alpine Secondary College)

Jirra felt the school had built a reputation for making good use of local resources to enhance student learning. She said, “We try and utilise our community as much as possible.”
Sometimes you get visiting teachers or visiting people [saying] ‘you’re almost like a private school with a public-school name’, in that we are lucky to have what we have” (Mathematics and Science leader, Alpine Secondary College).

Supporting STEM pathways

An extensive program of science electives was a very prominent mechanisms through which the STEM pathways were supported. The principal, STEM leaders, STEM teachers and students alike all attributed the school’s STEM success to this program to some degree. The program offered students a selection of theme based science units with titles like “Animal science”, “Earth science and meteorology”, “Simple machines”, “Forensics and psychology”, “Medical science”, and “Environmental engineering”. These units were aimed at either a Year 8/9 level or a Year 9/10 level, so students worked in mixed age groups and had the opportunity to accelerate into higher level units. Sally, nominated this as a key impactor on Alpine Secondary College students’ engagement in STEM, saying, “[The] elective system allows students to have some choice in their subjects, so they can pick things that interest them including in STEM subjects…many STEM subjects are hands on and have engaging activities” (Principal, Alpine Secondary College).

Peter, a teacher who was relatively new to the school considered the impact of the elective program on senior STEM participation:

The kids get amazing variety to choose from in science across Year 8, 9 and 10. They’re with kids in other year levels and stuff like that, but the subjects are more specialised, I think. Compared to a general Year 9 science where they cover everything across the year, and quite a bit of it might be boring. They’re actually doing a specific type of science for six months, and then they change to another. I just wonder sometimes if that maybe is the hook that gets them for Year 11. (Teacher, Alpine Secondary College).

A student agreed that the elective program had a positive impact on student engagement:

I think like the middle school classes, and that, that you do in science, they were really fun, and there's a lot of stuff to do. And when you do things, and then you learn about it, and then it makes you want to know more sort of. It's like good, I don't know, drawing you in. (Student 4, Alpine Secondary College).

Student enrolments suggested the science electives were popular relative to other subjects. Jirra, who had responsibility for timetabling, commented, “Most of our science classes have
25 kids in them… if you look at their first and second preferences, science is often first. They’re picking them because we try to make them as interesting as possible” (Mathematics and Science leader, Alpine Secondary College).

The vertical structure of the elective program provided the opportunity for students to accelerate, further supporting STEM pathways at the school. Jirra said, “At Year 10 … we encourage kids to accelerate into classes if they would like. So, for example... I have two accelerating Year 10s tackling Year 11 Specialist [Mathematics], and they are flying, they’re really loving it” (Mathematics and Science leader, Alpine Secondary College). Students who participated in the group interview spoke about completing a variety of Year 12 STEM subjects while in Year 11, including Chemistry, Biology, Psychology, and Mathematical Methods.

Significant effort was put into maintaining the broad offering of senior STEM subjects listed in Table 35 at the school. It was acknowledged that this breadth is quite unusual for a school its size. Peter commented, “It astounds me that a school this size has got Physics at both year levels, Chemistry, Biology and a Psychology, Specialist Mathematics, [Mathematical] Methods all running. It’s amazing.” (Teacher, Alpine Secondary College). In particular, the school made an effort to run STEM subjects that were pathway studies for tertiary courses. Jirra illustrated this:

We have Year 12 Chemistry, which has four students in it. Now that’s very small, but we thought well it’s such a key part for these kids and what they want to do, we would be doing them a disservice if we didn’t try and support it (Mathematics and Science leader, Alpine Secondary College).

**Skills focus**

The elective structure at Alpine Secondary College made it difficult to prescribe core science content, however the teachers focused on developing key STEM skills like problem solving, creativity and critical thinking. Jirra said:

We assess science inquiry skills in all of our science subjects. We have discovered, when we were aligning ourselves to the Victorian Curriculum, that most of our science subjects align themselves to the critical and creative thinking strand… And if it’s not that, then it’s ethical thinking for the biology subjects. (Mathematics and Science leader, Alpine Secondary College).
Tracy commented on the inquiry emphasis in the science course: “It’s extended investigation, and it’s good...kids have to really think and do a lot of research.” (Laboratory manager, Alpine Secondary College). Jirra said there was an emphasis on problem solving in mathematics courses, “We try and force problem solving, because I think it’s intrinsically built into mathematics anyway.” (Mathematics and Science leader, Alpine Secondary College). Craig agreed that this emphasis was important, providing this example:

Sometimes there needs to be an extended investigation. We do it in mathematics, we do a project where they use trigonometry, that we look at from the point of view of a soccer game… it’s really open-ended. So we do all the basics of trigonometry and then the kids that struggle, they’ll get the first page done, but the kids that want more they really can just run away with it. It’s a bitch to mark, takes ages, but it’s an assessment and it’s useful. (Teacher, Alpine Secondary College).

Reflecting on the emphasis on skill development in the school’s STEM courses, one student said:

Yeah. I guess we get a lot of [that] at the school, like ‘have a go yourself’, like the teachers sometimes will let you figure it out yourselves, which is good. They won't tell you straight up, it's more of a ‘figure it out and you'll get there in the end’. (Student 9, Alpine Secondary College).

**Valuing STEM**

A broad range of highly valued STEM related opportunities were available to students, despite Alpine Secondary College’s isolation and small size. Sally, the Principal, suggested that the extensive extracurricular offerings had impacted on the school’s success in STEM. She named an array of STEM focused excursions that the students had access to, including visits to a specialist metropolitan science school, and a life sciences learning centre in Melbourne. Jirra agreed providing access to these enrichment programs was a focus, while acknowledging the challenges that needed to be overcome to access these opportunities from Alpine Secondary College’s rural location. She said, “We try and support those as much as possible... to give our kids the best opportunities and experience they can, but obviously we can’t give them everything... we try and cover the costs through clever efficiency” (Mathematics and Science leader, Alpine Secondary College).

The students valued these STEM enrichment opportunities and appreciated the efforts made to provide them. One student said, “There have been a lot of science things, like excursion wise... we've had a lot of different excursions for technology, math, just STEM
subjects in general that we've been able to apply for at this school” (Student 10, Alpine Secondary College). Another commented:

So here they definitely try and push more experiences and opportunities on us, which I think that's why it's everyone is quite passionate about it…there's just more – it just seems like the school tries harder to make sure that we get the opportunities that we want, and offer more. (Student 3, Alpine Secondary College).

**Building STEM teacher capacity**

The STEM staff viewed the way they operate as a team, working together and supporting each other to deliver strong learning opportunities for the students, as a significant contributor to Alpine Secondary College’s STEM success. Nancy commented, “Teachers work well together and are genuinely interested in providing good lessons” (Teacher, Alpine Secondary College). Britta shared, “When I came here, I just got this impression that the staff worked really well together to make sure that we are all on the same page. I think that makes a difference.” (Teacher, Alpine Secondary College). Tracy said, “Everyone feels free to talk and discuss and come up with ideas, ‘Have you tried this? Why don’t you teach that or do this?’… Everyone’s pulling on their own experiences to help others. We’re all learning and evolving.” (Laboratory manager, Alpine Secondary College).

Alpine Secondary College’s STEM team had limited resources for professional learning, so they sought other ways of building teacher capacity. Jirra said, “We don’t have a massive professional development bucket, because we are a small school. So, we try and do webinars, those sorts of things.” (Mathematics and Science leader, Alpine Secondary College). Less experienced teachers were supported by more experienced staff: “The younger ones have stepped up and have obviously learnt from the older ones” (Mathematics and Science leader, Alpine Secondary College). Mentoring was particularly relied upon in supporting STEM teachers who have not taught a subject before. Jirra said that they try, “to put someone on a year level that’s taught it before.” (Mathematics and Science leader, Alpine Secondary College). Tracy said, “a lot of times people doing a Year 7 Science don’t have a science background, so there’s a lot of help from the ones who do have a science background.” (Laboratory manager, Alpine Secondary College).
6.4.5 Practice architectures enabling practices contributing to Alpine Secondary College’s STEM success

Participants at Alpine Secondary College highlighted a range of interrelated factors that facilitated the practices described in the previous section. These included the school’s rural location, small size, strong relationships, learning culture, and passion for STEM. The school’s timetable structure was also seen as a significant enabler. These enabling practice architectures themes are unpacked in this section and illustrated with excerpts from interviews and teacher comments from the anonymous survey.

Rural location and small size
The rural location of the school was used by the STEM team as a rich source of learning resources, with teachers speaking of working with the local power companies, water management authorities, airport, farms, and national parks to enhance the STEM education programs. While the school’s relative isolation was seen as potentially limiting access to some metropolitan STEM learning experiences, being part of a small rural community was used to overcome this limitation, with support from local Rotary and Lions clubs used to fund excursions to Melbourne and Canberra.

The small size of the school and classes was seen as facilitating supportive teaching. A student said, “We get a lot of like student-teacher time because it's so small.” (Student 5, Alpine Secondary College). Another student commented, “The teacher student ratio is pretty low in classes as well... So it's a lot easier to get access to teacher advice than it is in a larger school.” (Student 2, Alpine Secondary College). Tracy felt the small size assisted in maintaining high expectations: “I think being a small school particularly [helps] that because anyone who is lagging behind stands out” (Laboratory manager, Alpine Secondary College).

The small size of the school was seen as supporting STEM teachers in developing a deep understanding of each learner’s needs. Jirra said, “It comes down to we know our kids ...and we work with them on an individual level.” (Mathematics and Science leader, Alpine Secondary College). Students said that their STEM teachers had a good understanding of them as learners and individuals. One student said, “They know a lot about you ..., so they'll make your learning suited” (Student 7, Alpine Secondary College). Another offered an example of teachers responding to each student’s personal context: “They're also like, ‘we know you're busy that night, maybe do it this night’, and they can sort of help us with that.” (Student 8, Alpine Secondary College).
**Strong relationships**

The small size of the school and its community was also seen as contributing to the quality of relationships formed across the school, which in turn is seen as impacting a range of Alpine Secondary College’s STEM practices. One student said:

> You know a lot of the teachers personally. Even outside of school, at work, you see them at work … Know where most of them live … You could go and see them if you needed too. (Student 2, Alpine Secondary College).

Tracy said “Being a small school I think everyone knows everyone and everyone’s willing to help the younger kids, and the younger kids want to be involved.” (Laboratory manager, Alpine Secondary College). Another student observed, “Most of us have grown up around each other… Being such a small community and stuff, and most of us would play sport we’ll be like associating the same team, club together, so it makes it easy” (Student 5, Alpine Secondary College). Positive relationships between age levels were seen as having a positive impact on learning expectations. Peter commented in group interview:

> The younger kids actually see, that’s the best snowboarder in the school, or that’s the best mountain bike rider in the school, and they’re doing mathematics methods, and they’re doing physics, or Chemistry, and we’re lucky in that role modelling area of kids. (Teacher, Alpine Secondary College).

Strong relationships between teachers were also a feature of the STEM team. Tracy commented:

> All the staff have got a great sense of humour and are easy to work with, and we’re very forgiving of each other if we make mistakes, and that’s fine, we’ll get over it… No one’s afraid to ask questions. If I say, “I’ve never done this before. I don’t know what I’m doing,” then we’ll try and work it out together. (Laboratory manager, Alpine Secondary College).

**Strong learning culture**

There appeared to be an established culture of high expectations for learning held by the whole school community. When asked how teachers had contributed to the school’s STEM success, one teacher wrote in their survey, “Teachers have high expectations of the students and of themselves.” (Teacher survey 2, Alpine Secondary College). Britta said in the group interview:
I think there’s certainly a culture of high expectations that’s been built up, obviously over a number of years. The fact that kids do well is more than accepted, it’s actually looked upon as that’s really good that you do well. Kids that choose mathematics methods are not looked upon as being the smart kids, or the nerds for want of a better term (Teacher, Alpine Secondary College).

Students concurred with this view, with one student commenting:

I feel like a lot of people at school want to do well, we actually all really want to do well. And I feel like we're not selfish learners as well, we want the rest of the class to do well as well. We're not just focused on ourselves. (Student 9, Alpine Secondary College).

Further, this learning culture was seen as extending to staff. One teacher observed that teachers had a “willingness to learn new things alongside students” (Teacher survey 4, Alpine Secondary College). A student said of their STEM teachers, “You learn with them, ’cause they learn as well, so that – if they learn new things, they get interested about that, and then it kind of just all flows in. And that makes you excited to learn.” (Student 5, Alpine Secondary College). This learning culture was reflected across the whole school community. One teacher observed, “Education is valued by the wider community and it supports students’ success.” (Teacher survey 1, Alpine Secondary College).

**Passion for STEM**

The passion of the STEM teachers for their subject was a key contributor to Alpine Secondary College’s STEM learning culture. One teacher nominated “passion and knowledge for their subject” (Teacher survey 3, Alpine Secondary College) as how Alpine Secondary College teachers had contributed to the school’s success in STEM, while another wrote: “They are passionate about their chosen subject/s and this flows through to the students.” (Teacher survey 4, Alpine Secondary College). A student said of the STEM teachers: “The teachers are more engaging and enjoy it more as well I think.” (Student 8, Alpine Secondary College). Tracy said, “They’re passionate about their subject. They want the kids to do well because they love the subject so they want the kids to understand it” (Laboratory manager, Alpine Secondary College). In the teacher group interview, Peter offered this reflection on the STEM teachers at Alpine Secondary College:
I think maybe a key too is the staff enjoy what they’re doing as well. I walk in classrooms [and] it looks like the teachers are enthusiastic, and that wears off on kids. Just by osmosis, it just flows. The staff are enjoying what they’re doing, and enjoying the subject, and they’re keen. (Teacher, Alpine Secondary College).

The students also felt that the passion of their teachers encouraged similar enthusiasm for STEM in students. One student said, “If you have a teacher that’s passionate about what they’re teaching then the students are more likely to reciprocate that” (Student 2, Alpine Secondary College). Another said, “It seems like they’re really interested in the things that they teach, and then that has a trickle-down effect on the kids.” (Student 3, Alpine Secondary College).

This passion appeared well established at the school, and to be shared by the school’s leaders. Jirra explained:

I think that we have a history of it. There’s quite a strong history of mathematics and science, technology, engineering definitely along the way. In our previous Principal, he was very science-centric, and was very eager to get students involved in science, and I think that’s carried through… We’ve had people who are passionate about science, and passionate about learning… that’s just been maintained (Mathematics and Science leader, Alpine Secondary College).

The current leaders at Alpine Secondary College were also seen as strongly supportive of STEM education. One teacher commented that the “Principal and assistant principal both have teaching backgrounds in STEM subjects so are keen to see them flourish,” (Teacher survey 1, Alpine Secondary College). Another provided this comment in the survey, “It’s strongly spoken about the Principal herself teaches a mathematics class, so there’s direct support and understanding from her. STEM is not a ‘dirty word’ here,” (Teacher survey 3, Alpine Secondary College). Ultimately, there appeared to be an established STEM culture at Alpine Secondary College. A student commented, “I don’t know what it is specifically, but there seems to be a large STEM culture in this school. Well that’s the way it feels anyway. I feel like there’s a lot of people interested” (Student 3, Alpine Secondary College).
Unconventional timetabling and programming

In Year 7, students studied a standard compulsory program, with Mathematics, Science, and Technologies delivered as discrete subjects, similar to in most Australian schools (Marginson et al., 2013). Timetabling and programming from Years 8 to 10 was far less conventional. Students’ built their own programs as part of a vertical elective system. Students were required to study core Mathematics, English and Physical Education, however they chose the rest of their program including at least three units of science and one unit of technology or art across the three years. This system enabled students to pursue their particular interests in STEM. Inherent in the system was a potential for a student to study as few as 50 hours of science per year, up to 200 hours of science, compared to the national average of 139 hours per year (Thomson et al., 2017). This resulted in some highly mixed-ability, mixed age classes. Britta said, “I find that spread of ability is so huge in one class. You’ve got low-performing Year 9 students, and top-performing Year 10 kids” (Teacher, Alpine Secondary College). The elective structure also means students reach VCE with varied experience in STEM, as Britta noted:

Kids have come into [chemistry] with not the same exposure to chemistry… Having said that, that’s fine… even though they haven’t perhaps had a really dedicated and intense chemistry experience in 8, 9 and 10, they’re still choosing to do it, which I think is fantastic. They seem to be engaged and enjoying it which is great, really good. (Teacher, Alpine Secondary College).

6.4.6 Alpine Secondary College case summary

There were eight practice themes believed to contribute to Alpine Secondary College’s STEM success. Most significant amongst these was an emphasis on using hands-on activities, frequently associated with real-world learning contexts and place-based learning. These approaches were strongly evident in Alpine Secondary College’s science elective program, which were also seen as a mechanism to support STEM pathways and student acceleration in STEM. Alpine Secondary College also had an explicit focus on developing students’ STEM skills, as well as increasing students’ perceived value of STEM through providing STEM enrichment opportunities. Finally, the STEM teachers collaborated and supported each other to facilitate the professional learning of all members of the team.

These practices were enabled by practice architecture arrangements that belong to six themes. One of the most notable features was the provision and timetabling of elective subjects, including science and technology subjects, in Years 8 to 10, allowing students to
pursue their own interest areas and at their preferred level. Participants also felt that the school’s general learning culture and particular passion for science significantly facilitated practices leading to Alpine Secondary College’s STEM success. Finally, the school’s rural location, community, and relatively small size were described as enabling factors.

6.5 Coastal Secondary College

6.5.1 School Context
Coastal Secondary College, located near the coast in eastern Victoria, served families who lived in and around the surrounding national and state parks, coastal areas, and agricultural properties. In 2016 the school had a population of 277 Year 7 to 12 students, 137 boys and 140 girls, 2% of whom were Indigenous students, and no students with language backgrounds other than English (ACARA, 2019). These students were supported by the equivalent of 35.1 full-time staff (ACARA, 2019). The school had relatively new buildings, including STEM facilities such as a science education centre, a greenhouse, a plant nursery, and a developing agricultural education space.

In 2016, the school’s ICSEA was 1002 (ACARA, 2019), indicating the SES status of its community is similar to the national average of 1000 (ACARA, 2015). The town it was located in was approximately 170 kilometers from Melbourne, with a population of approximately 1160 people. The significant industries in the area were forestry, dairy farming, fishing, conservation, recreation, health and education.

There were three competing secondary colleges -- one government and two independent schools -- each just over 30 minutes away by car.

6.5.2 Cohort Profile
The STEM enrolment proportion for Coastal Secondary College at year 11 level during the study period was 45% and at year 12 level was 42%, above the average STEM enrolment proportions of regional and rural schools with communities of similar SES of 43% and 41% respectively. These students achieved an average study score of 28 across all subjects during this period, and an average study score in STEM of 28.66 (See Table 37) Schools from the same location and SES group had an average STEM study score of 27.84. The state mean study score for all VCE studies across all schools in all sectors is set at 30 (VCAA, 2017).

In year 7 the study cohort at Coastal Secondary College scored an average NAPLAN reading result of 531 and an average numeracy result of 523, below the Victorian averages of
548 and 551 for these tests respectively (ACARA, 2019). When in year 9 this cohort scored an average reading result of 562 and an average numeracy result of 563, showing that students made greater gains in numeracy than they did in reading. However, these results are again below the Victorian averages of 584 and 590 for reading and numeracy respectively.

Table 37

Mean enrolment proportions and achievement levels from 2014-2016 in Year 12 at Coastal Secondary College and its like-school group.

<table>
<thead>
<tr>
<th>STEM Subject</th>
<th>Coastal Secondary College</th>
<th>Like-schools group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean enrolment proportion</td>
<td>Mean achievement level</td>
</tr>
<tr>
<td>Further Mathematics</td>
<td>13.65%</td>
<td>28.12</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>2.81%</td>
<td>25.07</td>
</tr>
<tr>
<td>Biology</td>
<td>5.22%</td>
<td>33.08</td>
</tr>
<tr>
<td>Chemistry</td>
<td>1.41%</td>
<td>32.14</td>
</tr>
<tr>
<td>Physics</td>
<td>1.20%</td>
<td>25.17</td>
</tr>
<tr>
<td>Psychology</td>
<td>8.63%</td>
<td>31.65</td>
</tr>
<tr>
<td>Design &amp; Technology</td>
<td>1.00%</td>
<td>-a</td>
</tr>
<tr>
<td>Food Technology</td>
<td>7.83%</td>
<td>28.51</td>
</tr>
<tr>
<td>All STEM subjects</td>
<td>42%</td>
<td>28.66</td>
</tr>
</tbody>
</table>

* No exam results reported for Design & Technology for Coastal Secondary College from 2014-2016

6.5.3 Participant profile

The principal, the assistant principal, and four STEM teachers, as identified by their pseudonyms in Table 38, participated in interviews at Coastal Secondary College. In addition, three teachers took the opportunity to complete the anonymous online survey. Seven female and two male students participated in one of two student group interviews.
**Table 38**

*Coastal Secondary College staff interview participants and roles*

<table>
<thead>
<tr>
<th>Staff member pseudonym</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matt</td>
<td>Principal</td>
</tr>
<tr>
<td>Dave</td>
<td>Assistant Principal</td>
</tr>
<tr>
<td>Janak</td>
<td>Teacher (Mathematics &amp; Science)</td>
</tr>
<tr>
<td>Wil</td>
<td>Mathematics leader, Teacher (Mathematics)</td>
</tr>
<tr>
<td>Jill</td>
<td>Teacher (Mathematics &amp; Science)</td>
</tr>
<tr>
<td>Terry</td>
<td>Science leader, Teacher (Mathematics, Science)</td>
</tr>
</tbody>
</table>

**6.5.4 Education practices contributing to Coastal Secondary College’s STEM success**

Seven practice themes related to the school’s STEM success emerged from analysis of Coastal Secondary College’s data: High expectations with support; hands-on activities; real-world contexts; place-based learning; differentiated instruction; valuing STEM; and building STEM teacher capacity. What follows is an exploration of the educational practices captured by these seven themes, illustrated with excerpts from interviews and teacher survey comments.

**High expectations with support**

Supportive teaching practices, complemented by high expectations for learning, were felt to have contributed to the school’s STEM performance. One student commented:

> That’s what I found with my mathematics and science teachers. They’re like, ‘Look you’re not confident in it but you sure as hell can do really well in it’ and they pushed me. They’re like, ‘do it’ and kept pushing me until my confidence boosted up and then my marks went up because I knew that I could do it. (Student 3, Coastal Secondary College)

Students understood that their STEM teachers expect them to succeed, as these three comments illustrate: “I think our teachers just really want us to succeed” (Student 9, Coastal Secondary College); “They want us to do well” (Student 7, Coastal Secondary College); and “the teachers are really into your learning and they want to help you improve and that’s what’s really stood out to me in the Mathematics Science sections.” (Student 3, Coastal Secondary College). Janak said of the STEM teachers, “All the staff are pretty committed;
they want their kids to go well, and not just up to VCE level but right across.” (Teacher, Coastal Secondary College). Another student said of his STEM teachers:

Supportive environment and relationships are the biggest for me. That’s what’s really helped me, just support whenever you’re struggling. They sit down with you and just point you in the right direction and just get your confidence up saying ‘you can do this’. (Student 2, Coastal Secondary College)

STEM teachers at Coastal Secondary College were perceived to be generous and patient with the support they offered students. One student said, “If you don’t understand it [they’ll] explain it to you again and that’s probably what’s really good for me and that’s why I’ve continued doing Mathematics and Science.” (Student 3, Coastal Secondary College). Another student said, “I’m not the smartest at the top. But I always feel like I’ve got that help in hand, I’m not always behind. The teachers are always there for everyone which I think is really, really good.” (Student 5, Coastal Secondary College). The students recognised that the STEM teachers gave up their lunchtime and preparation time to help them, with one student saying, “The other day my science teacher spent his whole free with me, helping me, and [teacher name] does it all the time, just her whole lunchtime she’ll help me.” (Student 8, Coastal Secondary College). The STEM teachers also made themselves available after hours, during the homework club run by the school, and also by sharing their phone number and email address with senior students.

**Hands-on activities**

There appeared to be an emphasis on ensuring learning was active and ‘hands-on’ in both science and mathematics classes. Janak said, “Most of our staff are pretty hand-on; they’re not scared of doing pracs [practical activities] and doing activities in class.” (Teacher, Coastal Secondary College). Wil commented on how active the junior mathematics curriculum was, saying “There’s lots of activities so we do lots and lots of activities, there’s lots of equipment that we use” (Mathematics leader, Coastal Secondary College). The students appreciated the hands-on emphasis in STEM subjects when compared to other subjects they study. A student recalled hands-on activities in junior mathematics, “Little mini projects. It was actually really good... a little bit more arty...And it just got you a little bit interested” (Student 8, Coastal Secondary College). Another student commented:
I think with subjects I had, like English, they get really bland and kind of boring, you just have to do the course. So I know at the moment in chemistry… if we have questions, ‘oh come outside, we’ll do an experiment’ and cut up batteries and make elephant tooth paste, it just makes it interesting. And because he’s so hands … you can actually see it happen in front of you and just makes me understand, it’s so much easier (Student 9, Coastal Secondary College).

**Real-world contexts**

Beyond the engaging quality of hands on learning, Coastal Secondary College’s STEM team used real-world contexts to motivate students. Jill said, “So, with practical experiments and thinking tasks and a little bit of problem solving, making it realistic in life. So drawing, always drawing the distinctions of where this fits in life, where do we see it” (Teacher, Coastal Secondary College). Students described another teacher’s use of real-world contexts, “Our Chemistry teacher’s always saying about different reactions, what’s it used in. He knows stuff about cars, he saying it’s used in this certain thing and so you can relate it back to real life” (Student 2, Coastal Secondary College).

Students recognised the importance of this approach in STEM, for their learning and the learning of their classmates. One student said:

I had a group of friends who were like, ‘I don’t care, don’t care about school, don’t want to be here’, but then when they got to the subjects like Mathematics and Science where it could apply to what they’re learning, they were really engaged and their marks went up (Student 3, Coastal Secondary College).

Students spoke about how real-world contexts engaged them in learning. One student said, “We’re all going to buy cars and drive them… so it actually interests us. If we’re not wanting to do the mathematics, it’s still a real life situation where you’re like, ‘I could probably use this in life’” (Student 9, Coastal Secondary College).

**Place-based learning**

STEM subjects, as well as the wider school program, included STEM related place-based learning experiences, where students engaged in active learning in, and about, the local environment, industries and community. In many cases, this learning had an authentic purpose, where the work students did made a real-world contribution.
The STEM team frequently used the local area as a context for learning. Janak described the extensive range of local learning opportunities that have been used by the STEM teaching team:

We used to visit farms and see how they do agricultural science, Parks Victoria at certain year levels they’re heavily involved... so they do real initiatives to help the environment... Water Watch, we had a big partnership with them, so we used to analyse our local waterways and send in results to them about our health of our water system... we go to [place name] and we do rock pool studies over there which is fantastic. You can’t do that anywhere. Or you can just go out to the local creek here when it’s flowing well, you and do a lot of study down there (Teacher, Coastal Secondary College).

The students also valued these place-based STEM learning opportunities. One student said:

We did stuff there like organisms in the water and that kind of stuff, and then did different tests with that. I think that was pretty cool, just knowing that you can do that kind of test in local environments (Student 9, Coastal Secondary College).

The school ran an array of STEM related programs where the students participated in activities that are of value to the wider community. These programs were in addition to those delivered as part of STEM classes, and centred learning around an authentic, real-world purpose. These activities were frequently cited as contributing to the school’s STEM performance. Dave spoke about the school’s Broadening Horizons course where one of the projects was designing wildlife proof storage for campsites in consultation with Parks Victoria. He said:

The kids built prototypes of ways they could keep the wombats from ripping up people’s tents to get at food. They displayed the kids’ work over the Christmas break, so all the tourists would see what they’d been up to (Assistant principal, Coastal Secondary College).

Terry described the community learning program that all Year 9 students completed: “Year 9 do a sustainability area where they look at revegetating stockyard creek and they look at the hot house and garden up there” (Science leader, Coastal Secondary College). Dave described one impact of this community program: “We had a group last year, the year 9 community group, all of [location] no longer use plastic bags at any of the shops, they use environmentally friendly bags” (Assistant Principal, Coastal Secondary College).
students recalled working with Vic Roads (the Victorian government road transport authority) as part of this community program: “Vic Roads came over and we did projects for them. Some of the kids look at the railings on the side of the roads, the little green ones and how they work ... and signage and stuff like that” (Student 3, Coastal Secondary College).

The students interviewed recognised these community based programs as contributing to their engagement in STEM. One student said:

> It’s good because it gets the kids thinking about other things, like they went to [a local national park], they had a look at the birds, went to the beach and then they getting thinking, okay then, how can I protect the environment and then they’re deciding what are the jobs in the environment sort of thing (Student 3, Coastal Secondary College).

**Differentiated instruction**

Differentiated instruction in mathematics and science, was felt to have particularly impacted on the school’s STEM performance. Students felt that their STEM teachers knew them well and were able to adjust their teaching to meet their learning needs. A student said, “They know each individual’s level and what level of learning they’re at and their understanding of things and making things specific... people might be visual. Some people might be hands-on type of stuff” (Student 4, Coastal Secondary College). Another student commented on the STEM teachers’ ability to cater for all learners: “The students aren’t dumb they just learn in a different way and it’s good that the teachers can cater to that. They’re telling them we can do this, adjust it. Yeah, so we’ll change it to cater you” (Student 3, Coastal Secondary College).

In mathematics, differentiation was systematically structured into the learning programs, and the school attributed its performance in mathematics in part to this structure.

Dave said:

> Every kid in our school has an individualised program for 7 and 8. And from then on, we stream so 9 and 10 are streamed and they’re sort of ushered into better performing kids. Not pushed but it’s suggested to them to take on a tougher VCE program. So, we’ve seen our NAPLAN data in mathematics really improve from that” (Assistant Principal, Coastal Secondary College).

The Year 7 and 8 Mathematics program allowed for programs to be specifically tailored to the abilities of each student for each mathematics topic. The program was designed and developed in-house. Students sat a pre-test at the beginning of each topic and this was used to select their learning program. They then worked through this program at their own pace,
managing their own materials and resources, and self-assessing their own work. Teachers played the role of learning facilitator, occasionally providing instruction to small groups of students. A student offered this description of the program:

So, we had, I think it was a test you kind of did and then the teacher would put you into categories of where you’re sitting and you had to get, say, 30 stars. So, one activity would be worth three stars and you’d work up and then when you’d finished all the 30 stars you’d move to the next accelerated program. So, you’d keep moving up so then everyone was working at the level but still improving (Student 3, Coastal Secondary College).

In Years 9 and 10 students were divided into one of three mathematics classes according to their achievement levels in previous years. The higher achieving class was usually the largest in size, with students who had not achieved well in mathematics in previous years placed in a smaller sized class. Teachers continued to differentiate within these like-ability groupings. Jill said, “I’d have the methods kids, so I’d actually call them, you’re the methods kids and you’re the general kids and they would have different work within the same classroom” (Teacher, Coastal Secondary College).

Differentiation in Science was achieved more through task selection and flexible teaching rather than explicitly structured into the program as it was in mathematics. Jill spoke about the value of rich learning tasks: “We try and do really rich learning tasks in our school... So, it’s open to all the kids, no matter where their learning’s at” (Teacher, Coastal Secondary College). Janak highlighted the importance of teachers modifying assessment to ensure it is appropriate for all students: “You don’t judge them on the same test because that’s unfair. You’d have an individualised test or a smaller test” (Teacher, Coastal Secondary College).

**Valuing STEM**

The STEM teachers were strong advocates for STEM and STEM pathways. There were displays in and around the science and mathematics teaching areas that included STEM images, facts and information about STEM careers. The STEM teachers also made strong use of information evenings to promote STEM pathways to students and parents. Wil said, “We, as a faculty, tend to push pretty hard in terms of information nights and that sort of thing” (Mathematics leader, Coastal Secondary College). The STEM team particularly pushed for inclusion of mathematics in each student’s senior course. Wil commented, “The language is
that it’s expected... that students choose mathematics in Year 11 and they essentially have to have a valid reason why they wouldn’t” (Mathematics leader, Coastal Secondary College). The delivery of this message was facilitated by key staff members. Wil said, “Jill and Mike, the Year 12 coordinator and the head of senior school... They’re very good at pushing that fact that you need to do math, you need to keep your options open” (Mathematics leader, Coastal Secondary College). One student offered this comment about how STEM careers were promoted at Coastal Secondary College:

They kind of encourage you to try to, if it interests you... this is where a lot of growth is in careers and when you go out to get a career and when you start choosing what prerequisites you want obviously they’re probably ones that you want to focus around if you’re interested in it (Student 8, Coastal Secondary College).

Another student said that the STEM team’s advocacy for STEM impacted upon her, despite the fact she did not identify was a STEM student:

They are really keen to make sure that I stay in Mathematics and Science... The teachers [are] like, ‘Look it applies to everything, I know that you’re probably not keen on it but you can still do well in it and just have it as an option. ‘Cause you don’t know what you’re gonna do’, which is really helpful (Student 3, Coastal Secondary College).

**Building STEM teacher capacity**

The STEM success of the school was also frequently attributed to the qualities of the STEM teaching team. The STEM team saw itself as working well together. Wil said of the mathematics teaching team, “I always brag about them when I can to other people because I think that I am very lucky with my faculty group... they’re really good workers, they get stuff done and they’re really happy to have conversations about anything” (Mathematics leader, Coastal Secondary College). Janak spoke about the science teachers: “We generally know what the other people are doing... and we meet regularly and we discuss ways to implement or carry our curriculum across, and try to keep the kids engaged, try to keep it practical” (Teacher, Coastal Secondary College).

The collaboration of the STEM teachers was evident in the time they spent working together. They frequently met together formally. Separate professional learning team (PLTs) meetings were held for each learning area, but as many Mathematics teachers also taught Science, these teachers could meet as frequently as once a week. These structured meeting
opportunities were in addition to everyday, casual interactions, such as those described by Jill, “If I’m doing something and I really can’t nut something out, I’m more than happy to go over to another mathematics teacher and go, ‘Oh, look, can you have a look at this and tell, what am I doing wrong’” (Teacher, Coastal Secondary College).

The team were careful to share skills and teaching opportunities. Senior staff mentored new staff, and opportunities to teach higher level STEM subjects were shared. Jill spoke about the result of this strategic sharing, “We do have teachers now that, say if something happens to me or Janak, or Terry, we have teachers who are well equipped to be able to take on that class.” (Teacher, Coastal Secondary College). Students recognised the strategic nature of the STEM team in succession planning. One student offered this illustration, “Even when she was supposed to be retiring, in her last year, she was teaching the other teachers, this is what we should be doing, this is how to get kids going” (Student 3, Coastal Secondary College).

6.5.5 Practice architectures enabling practices contributing to Coastal Secondary College’s STEM success

Participants highlighted a range of interrelated factors that facilitated the practices described in the previous section. These included the school’s rural location, strong relationships, passionate STEM teachers, STEM curriculum design and documentation, STEM resourcing, and STEM staffing practices. There was also evidence of timetabling and programming arrangements that may also have facilitated practices that contributed to Coastal Secondary College’s STEM success. These enabling practice architectures themes are unpacked in this section and illustrated with excerpts from interviews and teacher comments from the anonymous survey.

Rural location

The rural location of the school’s community was seen to make students particularly receptive to certain STEM education practices. One student explained, “Most of us are from farms and stuff and we are hands on when we’re out there helping your dad or something, like tractors or something, so when we come to school we want it to be hands on again” (Student 8, Coastal Secondary College). Dave felt place-based learning approach was particularly suitable for Coastal Secondary College students, commenting, “I think it’s something that the kids are interested in, the outdoors. And they get more access to that here in the country” (Assistant principal, Coastal Secondary College). Janak said, “Most of our
kids are ... outdoorsy types, so they’re either off farms, some are town kids but others are living away from town so they’re into it, they know it” (Teachers, Coastal Secondary College).

Coastal Secondary College teachers made extensive use of the local area as a learning environment for their STEM education programs. Teachers described STEM trips to local beaches, national parks and the nearby desalination plant, as well as the significant STEM resources on and adjacent to the school site. The school had a large green house, a propagation area where they grew Indigenous plants for sale (sporting the school logo), a small area for agricultural studies, technology teaching spaces where the large and numerous sculptures decorating the school grounds were made, and a neighbouring creek that was used for water studies and as a regeneration project. Terry illustrated the benefits of these easily accessible resources, “They’re not in the classroom looking at pictures. We can go and have a real life look... Other schools don’t have that on their doorstep” (Science leader, Coastal Secondary College). Students also highlighted the benefits of their rural location. “When you live in the city you don’t have all those options. You can’t just go down to the park and test the water, or look at the creatures that are there” (Student 7, Coastal Secondary College).

While the rural environment was seen as a STEM education resource, the associated isolation was also acknowledged to have limitations, particularly when it came to accessing metropolitan learning experiences and professional learning. Janak said, “You can’t really go to the museum if they’ve got something really fantastic that’s relevant to what you’re doing. The time it takes, the cost is too much, so by the time you get there half the day is gone” (Teacher, Coastal Secondary College). Jill explained, “You travel three and a half hours and you go through the traffic...and then it’s something that you don’t get a lot of value out of. You soon decide I’m not going to go there again” (Teacher, Coastal Secondary College). Terry said, “It would be nice if the opportunities came to us” (Science leader, Coastal Secondary College).

**Strong relationships**

Quality relationships between the STEM teachers and students were seen as key to maintaining high standards and a supportive environment. Wil highlighted the importance of relationships, saying, “I think it’s just as much about relationships with the teachers as it is with what you’re doing, to keep them happy and engaged and wanting to be there” (Mathematics leader, Coastal Secondary College). The students also acknowledged the importance of good connections with the STEM teachers. One student commented, “The
teachers try to relate with you as much as possible so you felt comfortable asking questions and everything” (Student 7, Coastal Secondary College). Students also commented that these relationships also meant they did not want to disappoint the STEM teachers:

‘Cause they’d be like, ‘Oh, why have they dropped?’ And you’re like, ‘Damn, I’ll do better next time’. You do wanna [sic] impress them because you do have that relationship with them and you wanna [sic] show that they’re teaching’s not going to waste (Student 3, Coastal Secondary College).

The school’s small size was also seen as facilitating positive relationships and supportive teaching. One student noted, “The fact that we’re a small school you know all the teachers and you get along well with them and that makes it easier to ask for help as well I think. You’re not frightened of them at all” (Student 6, Coastal Secondary College). The STEM teachers also agreed on the value of a smaller school size for fostering relationships. Janak said:

I think because we are small we know our kids pretty well, and you can individually have a relationship and you know where they’re at, where they want to get to, so you’re sort of aware about their abilities and their motivations, and maybe even what they want to do in the future (Teacher, Coastal Secondary College).

In addition to the strong teacher-student relationships at Coastal Secondary College, the strong teacher-teacher relationships were felt to positively impact STEM education at the school. Jill said, “I think our staff is really open to each other and I don’t think we’re judgmental… we’re all encouraging to each other” (Teacher, Coastal Secondary College). Janak commented on the relationships between science teachers, “In the science area – pretty close” (Teacher, Coastal Secondary College). Students were also aware of the quality of relationships and collaboration between STEM staff. One student said, “I think there’s another little thing, there’s student to teacher relationships but the teacher to teacher is pretty strong” (Student 4, Coastal Secondary College).

Passion for STEM
The passion of the STEM teachers for their disciplines was seen as facilitating both student engagement and building teacher capacity. One student noted: “They have a genuine interest in the subject that they can give to the students. So obviously they’re going to be more
interested in it ‘cause it’s, like, so cool.” (Student 7, Coastal Secondary College). Another student said that the passion of the STEM teachers can help overcome a lack of student interest, saying:

Even if you’re not interested in it, you listen when your teacher’s so happy… You’re just entertained by that genuinely… They’re actually having a good time and smiling and asking questions and being all enthusiastic about it, then, like, ‘oh that’s cool’. (Student 9, Coastal Secondary College)

Jill commented on the passion shared by the STEM teachers:

If you get a group of mathematics teachers coming together who are all passionate about their subject, well of course you’re gonna [sic] have these really rich conversations going and just because, you know, we’re all passionate and we’re all really loving our subject. And the same goes for science as well, (Teacher, Coastal Secondary College).

Curriculum design and documentation

The STEM team were also strategic in the way they planned and documented their curriculum, and this significantly shaped the STEM education practices at Coastal Secondary College. Jill suggested their action was informed by research: “We use research to help us work out, you know, ‘what are we going to put time and effort into’ and whatever. So, it’s not just someone’s great idea, you know, we do, it’s based on research” (Teacher, Coastal Secondary College). They also adopt a pathways orientation to course design. Jill said:

We look at our VCE and say, ‘Okay, what are the things that we’re doing in VCE? What do they need to know how to do?’ And then we make sure that we tick up those boxes… and bring it right down into year seven (Teacher, Coastal Secondary College).

Janak commented on the importance of such an approach:

At VCE you’ve got to be able to just walk in and do the prac [practical activity] instead of being mollycoddled into it… if they’ve been skilled up in the middle school then they go in,… do something, get some good results, explain it without too much help (Teacher, Coastal Secondary College).
The STEM team make good use of documentation to support the work of colleagues and ensure the integrity of their courses. Dave acknowledged the strength of the STEM team’s curriculum documentation and communication:

We’ve never had a problem really with our mathematics and science, they’ve always been the most organised, the curriculum’s best documented, the, you know, all of those sort of things, passing on information from one year to the next. So, they’ve always been really good at that (Assistant principal, Coastal Secondary College).

Jill spoke about the role of the documentation in supporting all teachers of science: “We do have a really good thorough curriculum there so that any teacher can pretty much take up where another teacher left off ... and it’s all pretty well set out” (Teacher, Coastal Secondary College). Wil highlighted a benefit of the highly structured and well-resourced mathematics curriculum at the school: “The kids should be able to run themselves, almost... They know where the programs live ... They know where the tub of equipment is, so they’ll go in, grab the tub out and that’ll have everything in there” (Mathematics leader, Coastal Secondary College).

**Unconventional timetabling and programming**

Coastal Secondary College arranged its timetable to allow its Year 8, 9 and 10 students to engage in a full day community learning programs each week. Once a week students in these year levels spent a full day engaged in community service or outdoor education, often outside of the school grounds. These programs were felt by many participants to have contributed to the school’s STEM success, as discussed in the Place-based learning subsection of Section 6.5.4. This was not the only unconventional timetable feature. Students studied Mathematics and Science as discrete compulsory subjects from Years 7 to 10, similar to in most Australian schools (Marginson et al., 2013). However, up until the end of 2015, Science was an elective at Years 9 and 10, so all students in the cohort that generated the relatively strong STEM performance had Science as an elective in these year levels. Notably, participants did not reference these arrangements when discussing what they believed to have contributed to Coastal Secondary College’s STEM success.
**STEM staffing**

The STEM team had several long term staff members, at least one of whom had children attending the school. It also had several less experienced staff members, including Wil and Terry. It is worth noting that Wil grew up in the district and Terry had moved to the area for the lifestyle. The school had had difficulties recruiting STEM teachers with Jill commenting, “It’s really hard to get a good maths teacher,” (Teacher, Coastal Secondary College). The school had on several occasions had to support staff from other disciplines to teach science and mathematics classes, including retraining staff to teach mathematics. Dave said, “We’ve been really lucky with some of the local people who we’ve had for a long time” (Assistant principal, Coastal Secondary College). Wil was one example of this strategy, where he was teaching mathematics and leading the mathematics learning area, despite not being a qualified mathematics teacher. However, Jill still felt the school could strengthen the mathematics teaching team: “I’d like to get a good senior maths teacher to come on board to provide that depth, that level,” (Teacher, Coastal Secondary College).

### 6.5.6 Coastal Secondary College case summary

There were seven practice themes believed to contribute to Coastal Secondary College’s STEM success. The practices of differentiating instruction, particularly in mathematics, along with holding high expectations and building student self-concept, were seen as significant contributors to the school’s STEM performance. Hands-on activities were felt to be particularly suited to the students at Coastal Secondary College, and using real-world contexts and place based learning were believed to have impacted on Coastal Secondary College’s STEM success. Finally, Coastal Secondary College STEM teachers work closely together, supporting each other’s professional learning, and promoting the value of their subjects to students and parents.

These practices were enabled by practice architecture arrangements that belong to seven themes. Good use was made of the rich STEM learning environment and resources provided by the school’s rural location. Timetabling arrangements facilitating STEM related community and outdoor programs, as well as strategic curriculum programming in more traditional STEM classes, were felt to facilitate effective STEM education practice. Strong student-teacher and teacher-teacher relationships, STEM teacher passion, and efforts to maintain an effective STEM teaching team, were also felt to have enabled the STEM practices that led to Coastal Secondary College’s success.
6.6 What practices are believed to have contributed to the success of these high STEM performing rural schools?

The practices believed to contribute to each school’s success bore significant similarities from school to school. Table 39 lists all 10 of the practice themes apparent at the schools. It shows that eight of these themes were common to three or more schools, and only one theme was unique to a school. This section compares and contrasts how these themes manifested across the four sites.

Table 39

*Practices believed to have contributed to each schools’ STEM success*

<table>
<thead>
<tr>
<th></th>
<th>Sweeping Plains College</th>
<th>River Valley College</th>
<th>Alpine Secondary College</th>
<th>Coastal Secondary College</th>
</tr>
</thead>
<tbody>
<tr>
<td>High expectations with support</td>
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<td>✓</td>
<td>✓</td>
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<tr>
<td>Hands-on activities</td>
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<td>✓</td>
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<tr>
<td>Real-world contexts</td>
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<td>✓</td>
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<tr>
<td>Place-based learning</td>
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<tr>
<td>Differentiated instruction</td>
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<td>Supporting STEM pathways</td>
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<td>✓</td>
<td>✓</td>
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<tr>
<td>Skills focus</td>
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<td>✓</td>
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<tr>
<td>Valuing STEM</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Careers education</td>
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<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building STEM teacher capacity</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tbody>
</table>

6.6.1 High expectations with support

Common to all the school’s STEM teaching teams was that they held high expectations for learning, complemented by generous support. The way these expectations were communicated and the support offered differed somewhat from school to school. At River
Valley College, Coastal Secondary College and Alpine Secondary College, teachers and students spoke about an expectation for improvement, for example, “Achievement doesn’t necessarily mean attaining a perfect score, achievement in our school is always pushing a kid to go ‘did you do better than last time?’” (Jirra, Mathematics and Science leader, Alpine Secondary College). While it would not be true to say that Sweeping Plains College teachers did not expect improvement from their students, reference to high expectations was more often in terms of achieving at a high level, for example, “If something’s not to a good level we say we may need to have another go and repeat it.” (Paul, Technology leader, Sweeping Plains College). Additional support was offered by the STEM teachers in various ways at all schools. Most commonly, STEM teachers were willing to work with students during break times and after school. At Sweeping Plains College and River Valley College there was discussion about STEM teachers running extra classes in the holidays and part-time teachers helping senior students on their days off. Many teachers also gave the senior students their phone numbers and would offer assistance after hours via phone call or text. Several STEM teachers at River Valley College had established Facebook groups that both parents and senior students joined for additional support. At River Valley College and Coastal Secondary College support had been formalised through the establishment of afterschool homework clubs, both with a particular focus on mathematics. Of note, while there was a focus on supporting senior students, at all schools additional help was available and utilised by students of all ages.

6.6.2 Hands-on activities, real-world contexts, and place-based learning
As shown in Table 39, connecting learning to real-world contexts was believed to have contributed to the high STEM performance of all schools. An emphasis on hands-on activities, and the use of place-based learning, were seen as significant contributors at three out of four schools. There was an explicit focus on utilising the rich local resources at Coastal Secondary College to enhance STEM learning, using the environments adjacent to the school, as well as regularly taking students on short trips to national parks and beaches. Alpine Secondary College’s program seemed driven by the imperative to engage students in STEM learning, and in doing so turned to the resources available in local industries and environments. River Valley College’s STEM program seemed to evolve in a more organic manner, responding to student interest and local opportunities for learning.

In contrast, Sweeping Plains College’s participants spoke little about hands-on learning practices and did not feel that the immediate district offered much in terms of STEM
learning opportunities. Teachers and students did, however, speak about the importance and impact of relating content to real-world contexts. It is also arguable that Sweeping Plains College ran a very rich hands-on, real-world STEM learning program in the form of its technology oriented vocational education and training (VET) programs that all students participated in one day a week in Years 9 and 10. Participants did not, however, discuss this in terms of the hands-on, real-world learning that would most certainly be taking place in the program. Rather, they valued the VET program for highlighting the relevance of STEM to careers and the workforce.

6.6.3 Differentiated instruction, supporting STEM pathways, and a skills focus

Both Sweeping Plains College and Coastal Secondary College ran an extensive, highly structured, differentiated mathematics education program. While students at these schools worked on the same mathematics topic, they worked at their own ability level, choose many of their own learning activities, and were involved in the assessment and monitoring of their own learning. At River Valley College, Year 5/6 teachers provided structured opportunities for students to similarly direct their own STEM learning, though instruction in the secondary school tended to be differentiated less formally, in direct response to student need.

While Alpine Secondary College participants did not emphasise the role differentiation may have played in their school’s success, they felt that the school’s support of STEM pathways, particularly its elective science program, was a strong contributor to its success in STEM. Students chose from an array of semester long electives focused on a narrow and real-world aspect of STEM. These electives were offered to students from Years 8 to 10, giving students the opportunity to choose to study STEM that interested them, and pitched at a level that suited their learning needs. Participants also commented that this elective structure had prompted a focus on developing and assessing student STEM skills, including critical and creative thinking, rather than content knowledge, as students were all studying different types and amounts of STEM content. Alpine Secondary College was the only school that spoke about such an emphasis on skill building. It is worth noting that the cohorts at Coastal Secondary College and River Valley College also experienced a science elective program, but no participants at either of these schools mentioned these programs as contributors to the school’s STEM success. In fact, Coastal Secondary College had recently discontinued their science electives, and students at River Valley College noted that while they had electives they did not feel they had significantly contributed to their school’s STEM success.
Participants at three of the schools also felt the efforts taken to provide access to senior STEM subjects had contributed significantly to STEM success. Participants at Sweeping Plains College and Alpine Secondary College in particular noted that their schools made every effort to maintain STEM pathways in the senior school, including offering the mathematics and sciences that serve as prerequisites for entry into many tertiary STEM courses (VTAC, 2016), despite low student numbers and staffing challenges. At River Valley College the Principal described the extraordinary lengths she went to in order to ensure the school was able to offer Mathematical Methods, including altering timetables to recruit the local café owner as a qualified teacher. These three schools also felt the opportunities they provided to allow students to accelerate into VCE STEM subjects contributed to their STEM success. In contrast, participants at Coastal Secondary College lamented the school’s inability to offer subjects like VCE Physics and Specialist Mathematics.

### 6.6.4 Valuing STEM

Participants at each of the schools identified their practices for promoting the value of STEM and STEM education as contributing to their school’s success in this area. River Valley College’s STEM team ran STEM events at lunchtimes and afterschool, as well as participating in other highly visible STEM related activities. STEM students would regularly share their learning with younger students, raising the status of STEM education. Alpine Secondary College’s STEM team provided their students with opportunities and funding to attend STEM enrichment programs, further raising the value of these programs by requiring students to apply to participate. At Alpine Secondary College it was also felt that the role-modelling of senior STEM students to younger students further raised the perceived value of STEM. Coastal Secondary College’s STEM team strongly advocate for their subjects with students, parents and non-STEM staff. Sweeping Plains College staff adopted a narrower view, promoting mathematics and mathematics education through newsletters, information nights and special events. It is arguable, however, that the high profile of Sweeping Plains College’s Vocational Education and Training program also raised the utility value of STEM more broadly at the school.

### 6.6.5 Careers education

Related to schools promoting the value of STEM, participants at two schools, Sweeping Plains College and River Valley College, felt that their career education programs contributed to high STEM performance. Both these programs commenced in early secondary school.
Participants at both schools believed these programs contributed to whole school STEM success by supporting students to explore their aspirations and to understand the subjects that can help them achieve these goals.

6.6.6 Building STEM teacher capacity
Participants at each of the schools believed that approaches employed to build the capacity of STEM teachers had significantly contributed to their school’s STEM success. The elements described that facilitate professional learning in STEM education bore some strong similarities across the schools. Student learning was the focus of much professional learning, with teachers sharing insights about particular students or together pondering a problem encountered with student learning by a colleague. The STEM teams of these schools adopted a collaborative approach. Significant trust was noted between members of the STEM teams, with participants noting the easy, non-judgemental, and generous exchange of ideas amongst the STEM teachers. Given the relative isolation of the schools, STEM teachers made use of webinars, online resources, and readings as sources of external professional learning. Further, leaders at all the schools were seen as supportive of professional learning. There were some differences in the way teacher STEM capacity was built between the schools. Sweeping Plains College participants made use of a network of local schools to support professional learning. River Valley College participants spoke about being unsuccessful establishing such a network, and had instead formalised several mentoring arrangements within the school between teachers of related areas to support less expert staff. Alpine Secondary College school leaders structured their timetables to pair experienced and less experienced STEM teachers.

6.6.7 The inter-related nature of practices believed to have contributed to school STEM success
The practices described above where not executed independently of one and other, rather there was evidence that these practices were often viewed as enmeshed. Just as holding high expectations and offering extensive learning support, potentially viewable as two distinct practices, are presented in this thesis as one practice theme as participants almost universally presented these practices as intertwined, other practice themes were presented by some participants as somewhat connected and interdependent. For example, the significant support offered by STEM teachers to students seems to be perceived by some participants as dependent on the collaborative approach of the STEM teams. Veronica commented, “We talk
to each other a lot about, you know, what’s wrong, happening with this child or why, why they’re having troubles.” (Mathematics leader, River Valley College). The use of hands-on activities and real-world learning contexts was viewed by some participants as important for the school to be able to support STEM pathways. For example, Jill believed that the school’s ability to maintain STEM pathways was due to “the way we teach our year 9 and 10 science subjects. I think if you don’t encourage the kids to have a love of a subject in the junior years, that they won’t uptake it up into the senior years.” (Teacher, Coastal Secondary College). Careers education, alongside the capacity of the teachers, at the schools was also viewed by some participants as important to maintaining STEM pathways. Kevin said:

I think that’s one of the reasons as to why students might be choosing that [STEM subjects], because they’ve given good advice and backed up by the knowledge of the teaching staff themselves…they know there’s some strong passionate teachers in those areas and they choose accordingly (Principal, Sweeping Plains College).

Differentiated instruction was viewed by some participants as a primary mechanism for providing students with support while maintaining expectations. For example Wil described his school’s differentiated mathematics program in this way:

Everything that we do is specific to the level that you’re at and I think, in my head especially, I go, okay, well I’ve got a way that I can go fill in the gap, fill in the gap, fill in the gap, so that we’re kind of good to go after this level, while at the same time, pushing them further with the rest of the class type thing (Mathematics leader, Coastal Secondary College).

Other participants felt that hands-on activities contributed to supporting some students. One student commented:

The thing that I’ve really loved since the start ‘cause I’ve been here since Year 7, is its very hands on. So, no one, cause I’m not the smartest at the top. But always feel like I’ve got that help…I’m not always behind (Student 5, Coastal Secondary College).

The practice themes discussed in this chapter should be regarded as an intertwined bundle, rather than as clearly distinct themes, with the practices attributed to one theme potentially influencing the practices of another.

6.7 What practice architectures enabled the practices contributing to the success of these high STEM performing rural schools?

The factors that seemed to enable the practices contributing to each school’s success bore significant similarities from school to school. Table 40 lists all ten of the practice
architectures themes felt to enable the practices contributing to STEM success at the schools. It shows that six of these themes were common to three or more schools, and only two themes were unique to a school. This section compares and contrasts how these themes manifest across the four sites.

Table 40

*Practice architectures themes enabling practices contributing to school STEM success*

<table>
<thead>
<tr>
<th>Practice architectures themes enabling practices contributing to school STEM success</th>
<th>Sweeping Plains College</th>
<th>River Valley College</th>
<th>Alpine Secondary College</th>
<th>Coastal Secondary College</th>
</tr>
</thead>
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<td>Small size</td>
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<td></td>
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<td>Strong relationships</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Strong learning culture</td>
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<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Passion for STEM</td>
<td>✓</td>
<td>✓</td>
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<td></td>
</tr>
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<td>Curriculum design &amp; documentation</td>
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<td>Local school network</td>
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<tr>
<td>Unconventional timetabling and programming</td>
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<tr>
<td>Extensive STEM resources</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staffing STEM</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

6.7.1 Rural location, small size and strong relationships

Participants across the schools identified their rural location, strong relationships, and, in most cases, small size, as enabling the practices that led to their STEM success. These Practice Architectures themes were presented as intertwined. Strong relationships were sometimes presented as an artefact of the rural location, for example: “*Here you’ll be seeing teachers down the street all the time, you’ll be perhaps involved in the sporting clubs with them, in particular...that does help a little bit with the understanding and the trust and the support that you get,*” (Craig, Teacher, Alpine Secondary College). The relative isolation of the schools was felt to drive relationships, for example: “*You’ve got to rely on each other,*”
(Veronica, Mathematics leader, River Valley College). The small size of the schools and towns were seen to strengthen relationships: “Because it’s so small everybody’s sort of comfortable with everybody.” (Adrian, Teacher, Sweeping Plains College).

The rural location of the schools was seen to enable STEM practices in various ways. Each of the schools capitalised on the local rural resources for STEM learning in one way or another. The rural location was seen by some as priming students to learn STEM in hands-on, real-world ways, for example: “Most of us are from farms and stuff and we are hands on,” (Student 8, Coastal Secondary College). The isolation was viewed by some as a motivating factor for students to study STEM, for example: “That gives everybody the incentive and the drive and motivation to do the things they need to get them to somewhere else and achieve things.” (Adrian, Teacher, Sweeping Plains College). Participants at all schools recognised the rural location came with several costs, particularly in terms of accessing incursions and excursions, and external professional development.

The small size and/or strong relationships were viewed as facilitating the practices that maintained high expectations with support, as well as practices to build teacher capacity. Pragmatically, small classes were noted to make student progress easier to monitor, however others felt the capacity to offer individual support was much more significant, for example:

Rather than being more like a number, they know that they’re seen. That’s actually massive. I know it sounds small maybe, in words, but it’s highly critical. To be seen is to be valued, and to be recognised and to then value yourself. (Peter, Teacher, Alpine Secondary College).

Small classes and strong connection with classmates were viewed as making it easier to seek support and take learning risks in the classroom. Strong student-teacher and parent-teacher relationships were felt to ensure that each student received the support they needed. However, the negative impacts of small classes were acknowledged by participants. These included limiting class discussions, reduced data from experimental activities, skewed perceptions of learning progress, and even fewer opportunities for students to gripe about the teacher without her/him hearing.

6.7.2 Strong learning culture and passion for STEM
A strong learning culture was felt to enable effective STEM education at the various sites. River Valley College claimed a school wide learning culture of care and encouragement for all learners that was lived out by the STEM teaching team. Sweeping Plains College’s
documentation makes explicit high expectations held for learning, and participants reflected that the whole community values education and celebrates student success. At Alpine Secondary College both teachers and students held high expectations for learning. The strong learning culture at Alpine Secondary College was complemented by a passion for STEM and STEM learning, obvious in the teaching staff and readily transmitted to the students. Participants at Coastal Secondary College, spoke less of a pervasive learning culture and more about the passion and enthusiasm of the STEM teachers for their subject as facilitating student engagement.

**6.7.3 Curriculum design and documentation**
Coastal Secondary College participants described their careful and explicit curriculum documentation as a resource that maintained the strength of their STEM programs. In contrast, teachers at River Valley College noted their curriculum documentation was not thorough, but suggested that this facilitated teaching flexibility, for example: “I keep on changing, like if I write it down I would maybe become stale, you know, like I keep on going, oh, I could reinvent this and try things” (Veronica, Mathematics leader, River Valley College). Curriculum documentation was not a prominent theme at Alpine Secondary College or Sweeping Plains College.

**6.7.4 Local school network**
Sweeping Plains College’s strong relationship with other district schools facilitated their professional learning practices, their senior STEM pathways, their careers education program, and their technical training programs. It is worth noting that Coastal Secondary College had capitalised on a local network of schools to acquire VET resources, however it seemed these schools did not collaborate significantly in any other ways. Both Alpine Secondary College and River Valley College collaborated with nearby schools to run some STEM related programs, such as country firefighting training, however these partnerships were not attributed with facilitating school STEM success in any way.

**6.7.5 Unconventional timetabling and programming**
At each of the schools programs and timetables had been shaped to enable a variety of practices that they felt had contributed to their STEM success. School leaders at both Sweeping Plains College and River Valley College allocated significantly more time to mathematics learning in the early years of secondary school than the national average.
Timetables at had been arranged to allow students to participate in whole day STEM related learning at certain year levels, Sweeping Plains College with its VET programs, and Coastal Secondary College with its community and outdoor education programs. Alpine Secondary College used an extensive elective structure to allow students significant autonomy in their STEM pathways, and to facilitate student acceleration in STEM. Coastal Secondary College and River Valley College both had elective STEM programs during the time the study cohort was at school, however these programs were not as extensive and were not presented as impacting on these schools’ STEM success. River Valley College was the only school to run integrated STEM classes, however, this was only in Year 5 and 6.

### 6.7.6 Extensive STEM resourcing

Participants at Sweeping Plains College felt their extensive technology resources facilitated effective STEM education practices. Interestingly, Coastal Secondary College had access to similar resources associated with Vocational Education and Training (VET) but participants there did not highlight their use or impact on STEM success. At Alpine Secondary College resourcing was not seen as significantly impacting the STEM practices at the school. Tracy noted:

> We don’t have anything fancy, we don’t have a lot… And when you talk about coding and robotics, and there’s only so much kids can do, unless you buy enough sets for them all, which is an enormous big expense… [the STEM teachers at Alpine Secondary College] come up with a simple model…They just go old school a lot of times, (Laboratory manager, Alpine Secondary College).

Another teacher felt Alpine Secondary College was adequately resourced, writing in the questionnaire, “We have dedicated areas of the school for science, engineering and technology which are well resourced” (Teacher survey 3, Alpine Secondary College). Similarly, teachers at River Valley College suggested they worked in “an organised learning environment” (Teacher survey 1, River Valley College) and that “although resources are old, staff and students look after them as they know we won't get anything if it's damaged” (Teacher survey 4, River Valley College). One River Valley College STEM teacher wrote in the survey, “We often work with what we have rather than purchasing new and expensive equipment” (Teacher survey 2, River Valley College). The lack of expensive resources was not necessarily viewed as an impediment, with Stuart arguing that expensive technologies were not required for STEM education: “You don’t need a lot of expensive gear to run a good
STEM program. In actual fact it’s worse because then the kids think in order to do STEM subjects you’ve got to have expensive gear.” (Stuart, Science leader, River Valley College)

6.7.7 STEM staffing
There were several enabling factors highlighted at three of the sites relating to the staffing of STEM education. Principals at these sites spoke about their efforts to ensure they had appropriately skilled and qualified STEM teachers. At River Valley College flexible work arrangements, alongside efforts to accommodate the needs of STEM teachers’ whole families, were used to attract and keep quality STEM teachers. Staff from other disciplines at both Sweeping Plains College and Coastal Secondary College had been successfully trained to teach STEM subjects, and leaders at Sweeping Plains College had also employed and had retrained local tradespeople to fill teaching technology teaching vacancies. Leaders at Sweeping Plains College also capitalised on collaborative relationships with other nearby schools to support teacher development and run STEM subjects. Staffing was not highlighted as a significant factor or concern at Alpine Secondary College. However, there was discussion of recent STEM staff turnover, and of the benefits of the continuing presence at the school of a recently retired staff member.

6.7.8 The inter-related nature of the enabling practice architectures
While the practice architectures enabling practices contributing to rural school STEM success were discussed separately in this section there were notable overlaps between them. The close relationships within the school community and with the wider community were seen to reinforce the strong learning culture at Sweeping Plains College. The rural location of River Valley College, with its various local STEM industries, were believed to contribute to value the community placed on STEM and thus the STEM culture of the school. The passionate STEM team was often described as the driving force behind the unconventional STEM programming at Alpine Secondary College. The rigor of curriculum design and documentation was discussed alongside the challenges of STEM staffing at Coastal Secondary College. Though not explicitly noted, it would be reasonable to speculate that the close relationships and trust both within and beyond the school communities, were significant in the adoption and success of the various unconventional STEM programs employed across the schools.
6.8 Summary

The chapter has presented a multi-case study of high STEM performing rural schools. While having rurality and relative isolation in common, these schools differ from one and other in the relative wealth of their communities, their surrounding natural environments, and the local dominant industries. As such, they demonstrate that STEM success is achievable in a range of rural contexts.

This research explored practices believed to contribute to the STEM education success of each school, however participants were left to determine what STEM meant to them. It is apparent from this collection of cases that STEM was most frequently interpreted as Mathematics and Science education by teachers, students and principals alike. Also of note across the cases was that some aspects of practice were viewed as un-extraordinary and just part of the way things are done, so not worthy of extensive comment. For example, two of the schools allocated well above the national average time to the study of mathematics, and well below the average to studying science, yet no participant chose to comment on the potential impact of this time allocation. This may be because this time allocation was not viewed as contributing to STEM success, or because the time allocation was not perceived as extraordinary by the participants.

All of the schools attributed their STEM success to an array of practices, and a collection of Practice Architectures that enabled these factors, rather than to any single intervention or measure. Practices believed to contribute to STEM success, and the Practice Architectures felt to enable them, bore similarities across the four cases. Practice themes common to all four sites were high expectations and support, real-world learning contexts, valuing STEM, and building STEM teacher capacity. Practice Architectures that seemed to be enabling these types of practices at all four sites were the school’s rural location, strong relationships, and some unconventional timetabling and programming arrangements.
Chapter 7: Multi-case analysis of practices contributing to rural school STEM success

7.1 Preamble
This chapter discusses the practices evident at the high STEM performing rural schools described in Chapter 6, situating this study’s results in the literature. The discussion is organised around elements prominent in the STEM education research literature, and in Australian school STEM policies. These elements are considered under the broad headings of capabilities, engagement, education practices, equity, trajectory, and educator capacities. In doing so, it raises questions about the importance of practices promoted as contributing to effective STEM education to the STEM success of rural schools. This chapter then examines the practices of these high STEM performing schools that are not readily encompassed by these elements and considers their alignment with the extant educational literature more broadly. This chapter identifies practices worthy of further STEM education research, and for consideration in policy development to support effective STEM education, particularly in rural schools.

7.2 Elements promoted as contributing to school STEM success
There are six broad elements promoted as contributing to school STEM success: capabilities, engagement, education practices, equity, trajectory, and educator capacities (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). As discussed in Chapter 2, each element is strongly represented in the STEM education literature, and is reflected, to a greater or lesser extent, in the STEM education strategies of the various Australian jurisdictions. This section uses these elements as a lens to examine the practices of the high STEM performing rural schools involved in this study.

7.2.1 Capabilities
The STEM literature promotes the view that STEM knowledge is connected to real-world applications, that it is interdisciplinary, and that it is dynamic and expanding (Asunda, 2014; Bybee, 2013; Roth & Van Eijck, 2010; Zollman, 2012). However, this view had only limited representation across the high STEM performing schools studied.

Students and teachers at all schools recognised the importance of making connections between learning in STEM subjects and real-world applications. In some cases, learning was set in real-world contexts, such as raising cattle at River Valley College, monitoring water
ways at Coastal Secondary College, or an entire elective based around medicine and health care at Alpine Secondary College. However, just as often it seemed a connection was made to real-world applications as a post hoc justification for something taught in the abstract, with students at several sites talking about their teachers giving practical demonstrations and examples of content that had previously been explored. A student comment from River Valley College illustrates this:

We learn concepts and he blasts through it and makes sure that we understand and then he brings out, he always has something. Like … he had brought in an alternator or a bunch of copper tubing or whatever else and shows us these concepts in actuality. (Student 2, River Valley College)

While STEM knowledge was generally presented at the four sites as at least connected to, if not contextualised in, the real-world, it was rarely explored as interdisciplinary at any of the sites. Knowledge seemed to be considered as bound by disciplines, rather than fluid and interconnected across and beyond the disciplines, as Roth and van Eijck (2010) argue STEM knowledge should be viewed. All schools delivered their secondary STEM curriculum as separate subjects, as do the majority of Australian secondary schools (Marginson et al., 2013). Sweeping Plains College’s STEM curriculum was strongly structured along traditional disciplinary lines, with the only acknowledgement of interaction between the disciplines being the importance of numeracy in technology and engineering subjects. Coastal Secondary College’s classroom STEM curriculum was similarly bound, with much of the junior STEM curriculum explicitly designed to prepare students for the associated senior school subjects. Alpine Secondary College’s elective program deliberately broke down the boundaries between the separate science sub-disciplines, however the boundaries between the STEM disciplines were left largely intact. Of the schools, River Valley College was most likely to incorporate learning experiences that demonstrated some connection between the STEM disciplines, such as raising chickens as an investigation task in mathematics, or graphing and calculating rates of decay in science. However, even here any subject integration did not appear to aim to explore STEM knowledge as interdisciplinary, but instead was capitalising on opportunities to build disciplinary knowledge. Even the integrated STEM subject in Year 5 and 6 at River Valley College was viewed as a more efficient way of delivering the curriculum of the separate disciplines, as this quote illustrates:
I suppose it was because the curriculum was pretty crowded so you’re trying to get in the literacy and numeracy and SOSE [Studies of Society and the Environment] and all those sort of things, so that annoyed me. And then a few years ago, probably about five or six years ago started looking into the fact that there was a STEM approach where you’re integrating everything and that’s sort of the way I wanted to go. (Stuart, Teacher, River Valley College)

There was also evidence that a relatively naïve instrumentalist view of STEM knowledge predominated across the sites. An instrumentalist view sees knowledge as comprised of sets of disconnected facts, skills and processes to be applied to achieve a particular end (Ernest, 1989). The differentiated mathematics programs at Sweeping Plains College and Coastal Secondary College strongly reflected this view, with students working through increasingly challenging exercises in distinct aspects of mathematics, often with the only end being to progress along a knowledge and skills continuum. An instrumentalist perspective was also reflected in teacher comments where junior STEM curriculum was justified as preparing students for senior STEM subjects by instructing students in perceived pre-requisite skills and knowledge. Such naïve views of STEM knowledge are associated with students developing a narrow and limiting view of the nature of STEM, particularly science and mathematics (Chesky & Wolfmeyer, 2015; Ernest, 1989; Sutton, 1996). There was little evidence at any of the schools of STEM knowledge being viewed as interconnected, dynamic, and uncertain, perspectives generally regarded as more sophisticated (Ricco et al., 2009).

The various Australian STEM education policies task STEM education with building skills in creativity, critical thinking, and problem solving (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). The case study schools seemed to address this task to varying degrees. At Sweeping Plains College there was minimal reference to building any of these skills. Similarly, Coastal Secondary College’s standard STEM subjects were not presented as developing these skills, but rather focused on developing disciplinary competencies viewed as necessary for success in senior years. However, Coastal Secondary College’s community-based programs were aimed at critical exploration and problem solving associated with local issues. Alpine Secondary College participants spoke about explicitly assessing and reporting on student progress against the Australian Curriculum Critical and Creative Thinking general capabilities (ACARA, 2017) through their elective science program. At River Valley College these skills seemed to be address more organically, with students engaged in a variety of current and local critical investigations and problem solving tasks through both their science and mathematics curriculums. It is worth noting that participants from schools claiming to
develop these skills did not choose to elaborate on how these skills were nurtured, beyond just providing the opportunity to exercise these skills. This absence of detailed exploration may reflect some of the complexities noted in literature around explicitly describing and building skills such as creativity and critical thinking for students (Furness et al., 2017; Kaufman & Beghetto, 2009; Nardi, 2017).

On the whole, the construction of STEM knowledge and the development of STEM skills as described in the research literature were not strongly emphasised as a contributing factor in the schools’ STEM success. There was consensus on the importance of viewing STEM knowledge as real-world, but little emphasis on it being interdisciplinary or unstable. Participants at three of the schools highlighted the influence of some rich problem solving opportunities in their curriculum, however only participants at one school claimed an explicit focus on developing critical and creative thinking as a contributing factor to their high STEM performance.

7.2.2 Engagement

Many of the schools’ practices believed by participants to contribute to STEM success were seen to be impacting on student dispositions towards STEM and STEM education. The impacts described align with various motivational factors shown to influence STEM engagement in the research literature. Table 41 summarises the motivational impacts participants described for the practices described in Section 6.6 ‘What practices are believed to have contributed to the success of these high STEM performing rural schools?’ of this thesis. Table 41 shows that the majority of practices were believed to act by impacting on the perceived value of STEM learning tasks to the student, as well as the student emotional response to learning in STEM. The table also shows that motivational factors of self-concept, autonomy, relatedness, mind-set and goal orientation, were associated with fewer practices. However, it is important to note that the practices impacting these aspects of motivation were regarded as contributing significantly to STEM success by the schools that employed them.

The practices believed to have contributed to each school’s STEM success were most frequently described as impacting task value. Task value is the value a student attaches to a learning activity or the outcome of an activity (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). Many practices, such as real-world and place-based learning, careers education, and some practices associated with promoting the value of STEM, were felt to improve the perceived utility value of STEM and STEM education, by demonstrating the connection of learning to students’ lives or potential careers. Real-world contexts, and place-
based learning, as well as the elective science programs categorised in the supporting STEM pathways practice theme were thought to improve the interest value of STEM learning. Finally, setting high expectations fostered a culture where doing well in STEM was celebrated at the schools, raising the attainment value of STEM tasks. Task value has been found to be predictive of engagement with further study in science and mathematics (Guo et al., 2017; Guo et al., 2015), lending credence to participants’ beliefs that these practices contributed to their schools’ STEM performance.

**Table 41**

*Practice themes believed to contribute to student engagement in STEM by motivational construct*

<table>
<thead>
<tr>
<th>STEM Practice theme</th>
<th>Motivational factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Self-concept / self-efficacy</td>
</tr>
<tr>
<td>High expectations with support</td>
<td>✓</td>
</tr>
<tr>
<td>Hands on activities</td>
<td>✓</td>
</tr>
<tr>
<td>Real world contexts</td>
<td>✓</td>
</tr>
<tr>
<td>Place-based learning</td>
<td>✓</td>
</tr>
<tr>
<td>Differentiated Instruction</td>
<td>✓</td>
</tr>
<tr>
<td>Supporting STEM pathways</td>
<td>✓</td>
</tr>
<tr>
<td>Valuing STEM</td>
<td>✓</td>
</tr>
<tr>
<td>Careers education</td>
<td>✓</td>
</tr>
</tbody>
</table>

Self-concept and task-value have been found to interact to predict engagement and achievement in science education (Guo et al., 2017). Self-concept is a student’s belief about their abilities in a specific domain (Murphy, MacDonald, Wang, & Danaia, 2019, see Appendix B), such as STEM. An individual needs to value STEM and STEM education, as well as possess high self-concept in STEM education in order to engage in STEM learning. Only two of the practice themes were described as impacting STEM self-concept: differentiated instruction and high expectations with support, particularly in mathematics. Mathematics differentiation was seen as a way to ensure all students experienced success in mathematics, building their confidence and self-concept. Practices associated with high expectations and support also emphasised self-concept in mathematics. Support was available in all the STEM disciplines across the schools, however, it was most commonly described as being required, and having impact on student self-concept, in mathematics. At River Valley College, after-school support was introduced to meet a need for extra help with mathematics homework. Coastal Secondary College students spoke about their mathematics teachers both pushing them and supporting them so that they grew in confidence in mathematics.

Many of the practice themes were also described as impacting students’ academic emotions. Hands on activities, and River Valley College’s science elective program, were described as generating positive academic emotions such as enjoyment and excitement. The differentiation of mathematics at Coastal Secondary College and Sweeping Plains College was presented as mitigating students’ negative emotions, minimising boredom for advanced mathematics students and reducing anxiety for less confident or less able mathematics students. When discussing practices associated with high expectations with support, STEM teachers spoke about the care they took in managing students’ emotions, working to minimise anxiety associated with attempting tasks, and to maximise pride in any and all achievements. Research has shown that academic emotions predict engagement and achievement in STEM, particularly in mathematics (Larkin & Jorgensen, 2016; Pekrun et al., 2017; Simon et al., 2015), to some extent legitimising claims of participants in this study that the emotional impacts of these practices contributed to school STEM success.

Though relatedness was only seen to be impacted by two of the practice themes, it was emphasised as a significant contributor to the STEM success of each school. Relatedness includes a student’s sense of connection to peers, teachers, their school, and the wider community (Murphy, MacDonald, Wang, & Danaia, 2019, see Appendix B). Relatedness was viewed as a key aspect of holding high expectations with support. Participants spoke about teacher-student relationships facilitating the setting of achievable expectations and
offering personalised support for each student. Several students spoke about the motivating aspect of their relationships with their STEM teachers, noting that they did not want to disappoint their STEM teachers. The motivating impact of teacher-student relationships on learning has been noted in the literature (Bieg et al., 2011; Wang & Holcombe, 2010), and teacher support is seen as particularly impactful in rural schools (Hardré, 2011; Watson et al., 2016). Not apparent in the literature was the motivating impact of relatedness upon STEM teachers, with STEM teachers describing their relationship with students and their families as a motivating force behind their efforts to drive and support student learning. Place-based learning was described as engaging students by capitalising on their relationships with the outdoors, with local industries, and with their communities, aligning with research suggesting that using such community connections can promote rural student engagement in STEM learning and learning in general (Barley & Beesley, 2007; Halsey, 2018; Hardré et al., 2009; Semke & Sheridan, 2012). There is relatively limited research into relatedness as a motivating factor in STEM education (Rosenzweig & Wigfield, 2016), however the evidence that is available supports exploring its influence further (Murphy, MacDonald, Wang, & Danaia, 2019), and the findings from this study adds support to its potential value.

There were several aspects of the identified practice themes that supported student autonomy, such as students directing and monitoring their learning in the differentiated mathematics programs, students choosing their own science electives at Alpine Secondary College, and students determining their own projects in many of the place-based learning activities. Supporting student autonomy has been shown in the literature to improve academic engagement and achievement in science and mathematics subjects (Carmichael et al., 2017; Hagger et al., 2015; Jungert & Koestner, 2015). Despite the presence of, and research evidence for, supporting student autonomy, participants only occasionally highlighted the autonomy aspects of practices as contributing significantly to student engagement, instead emphasising the impact of other motivational factors.

Other motivational factors were relatively absent in participants’ accounts. When discussing high expectations and support, participants felt a focus on improvement rather than performance was important for improving academic achievement in STEM, aligning with the findings of Bostwick et al. (2017) in mathematics. However only STEM teachers at River Valley College spoke explicitly about adopting a growth mindset approach. There was some evidence of students being involved in goal setting, particularly associated with the differentiated mathematics programs, though these goals seemed to be focused on performance, such as meeting benchmarks and targets, rather than being true mastery goals,
more often associated with academic engagement and achievement in STEM (Miller et al., 1996; Simon et al., 2015).

7.2.3 Education practices

Much of the STEM education literature suggests that effective STEM education practices present the curriculum as integrated, and engage students in inquiry learning (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). Further, there is a common understanding, with some supporting research evidence, that STEM education practices should incorporate the use of digital technologies, such as robotics and coding, and external partnerships, with industry, community groups, and tertiary education institutions. None of these could be regarded as dominant features of the STEM education practices believed to contribute to the STEM success of the schools in this study. However, integrated curriculum, inquiry learning, digital technologies, and external partnerships did feature to varying extents across the sites studied.

**STEM integration**

While an integrated approach to STEM was not prominent at any of the sites, there was evidence of various forms of STEM integration at several schools. Only River Valley College offered a multidisciplinary STEM program, and, even there it was only offered to Year 5 and Year 6 students. This program organised integration around themes, such as “waste” or “inventions”, in a way that Moore (2014) would describe as content integration, where synergies between the different STEM fields are identified to design learning tasks that address learning objectives from multiple discipline areas. This integrated approach to STEM was believed to engage students, with one comment being “I certainly know the kids really like the integrated approach” (Stuart, Science leader, River Valley College), aligning with research suggesting integration positively impacts student interest and motivation (Honey et al., 2014). STEM integration was not structured in this way in the secondary school at River Valley College. This may have been due to a lack of programming time, as illustrated by this comment: “I know the teachers are keen to do it and I think it’s probably just a matter of us sitting down and working on it,” (Stuart, Science leader, River Valley College), a common barrier to effective integration (Rennie et al., 2012). Alternatively, it may be associated with the personal preferences of the secondary school teachers, “I prefer to teach my science and teach my mathematics pure and then when I do my puzzles or my science experiments I pool it in when it’s appropriate” (Veronica, Mathematics leader, River Valley College), or a belief
that integration requires multidisciplinary knowledge that the secondary teachers do not have, as implied by this comment: “[Stuart can integrate STEM] because he’s mathematics and science he can do STEM at five six and get it to really work. But … his real passion is STEM,” (Lee, Numeracy leader, River Valley College). These comments suggest that integration requires a real commitment from staff, as well as strong multidisciplinary knowledge, as found by Rennie et al. (2012).

Despite a lack of programmed integration in River Valley College’s secondary school program, there was significant opportunistic integration, with skills and content from one discipline being introduced into the teaching of another as the opportunity arose. For example, graphing was taught through science classes, coding was integrated into mathematics classes, and chicken life-cycles were explored in mathematics classes. This form of integrated is advocated for by Williams (2011), who calls for interaction of the separate disciplines where it will enhance student learning, rather than programmed integration. At River Valley College this type of integration was facilitated by STEM teachers being experienced in teaching both mathematics and science, and the small teaching staff regularly communicating and collaborating.

The community-based programs at Coastal Secondary College represent yet another variant of STEM integration. Here, the content of individual disciplines were taught through a traditional classroom program in separate subjects, while the projects based in the local community and environment required students to adopt an interdisciplinary approach. Bybee (2010) advocates such a model of integration, where the individual STEM subjects are maintained and supplemented by shorter integrated instructional units shaped around a personal, social or global issue. The Vocational and Educational Training (VET) programs at Sweeping Plains College could be seen as another example of this form of integration, with students applying capabilities acquired in traditional classrooms in interdisciplinary vocational contexts. Career preparation such as VET requires an integrated approach (Klein, 2010).

Teachers at two schools spoke about the difficulties of effectively addressing mathematics outcomes through an integrated STEM program. Kim, numeracy leader at Sweeping Plains College reflected on a Year 7 and 8 integrated program the school had run in the past but had since abandoned. She had enjoyed being involved in the program and felt that this program was “good to kind of motivate them” because “they feel more excited and they can see some use of that,” (Kim, Numeracy leader, Sweeping Plains College). However, she felt it resulted in more limited mathematics skill acquisition as students “don’t have
enough practice and reinforcement.” Kim also felt there was a mismatch between mathematics syllabus requirements and the type of mathematics required by integrated projects. She offered this illustration:

So like we’d go oh yeah we’re doing that, we’re going to put measurement into it ‘cause [sic] they’ll do cooking like, but when you’re in Year 7 and 8 the skills that they need in measurement are not related to that sort of thing. So the amount of mathematics skills they got out of it weren’t very strong. So, yeah, you were kind of giving up mathematics time for not much. (Kim, Numeracy leader, Sweeping Plains College)

Stuart, science leader at River Valley College, acknowledged similar difficulties with integrating mathematics. He noted that, while he felt they successfully met some mathematics outcomes through the program, such as measurement and data, they had modified their program to better address the mathematics curriculum requirements:

The only trouble we found was trying to put the mathematics into some of the programs. I was a bit worried that they were losing … some of their basic essential mathematics skills, so we sort of tweaked our program a bit and we would, you know, so like a double period of what we would call STEM the first period might be more number fluency and like number skills and in the second one that’s where we’d be doing more of your science technology engineering. (Stuart, Science leader, River Valley College).

These reflections from Kim and Stuart suggest that, in practice, STEM integration may not serve mathematics as well as the other disciplines, as previously argued by English (2016) and Coad (2016).

Though some STEM integration occurred as some of the schools, an integrative approach to STEM education was not a significant part of the curriculum at any of the schools. Further, where, STEM integration occurred, the practice was not viewed as a major contributor to the STEM success of any of the schools.

Inquiry-based learning
Similar to integration, inquiry-based learning, where students are engaged in solving complex and ill-defined problems (Fielding-Wells et al., 2014), was not a dominant feature of STEM practice across the schools, and nor was it attributed significant influence on any school’s STEM success. However, also like integration, aspects of the practice were evident at several of the sites in a range of forms.
Gee and Wong (2012) offer a taxonomy of inquiry-based learning elements that can be used to consider the strength of STEM inquiry practices at the four schools. This taxonomy suggests that inquiry-based teaching and learning includes the following four elements:

1. Applications – students explore real-world applications and concepts relevant to society and students’ lives;
2. Hands-on – students engage in practical, hands-on activities;
3. Interaction – students explain their ideas and share opinions; and
4. Investigations – students choose, design, and direct their own investigations.

(adapted from Gee & Wong, 2012, pp 306-307)

Applying this taxonomy to the practices of the schools it can be seen that many of the elements that make up inquiry learning were present at the sites and were aspects of practices believed to contribute to school STEM success. The Applications element was evident at all schools, with teachers and students describing the positive impact of connecting STEM learning to real-world contexts and students’ lives. The Hands-on elements was viewed as a significant feature of all schools’ STEM curriculum other than Sweeping Plains College’s, though even there it is reasonable to view the extensive VET program as reflecting this element. The Interaction element was not emphasised as a contributing factor by participants, but instead was presented as an assumed norm, with student collaboration and contribution spoken about as common place. While these three elements of inquiry were relatively common place across the sites, the fourth element, Investigations, was less so.

The presence of the Investigations element varied between the four schools. It was largely absent from the interview transcripts of participants from Sweeping Plains College. There was some evidence of this element at Alpine Secondary College with teachers describing open-ended complex problem solving tasks and students commenting on an emphasis on independent learning, for example, “I guess we get a lot of sort of that at the school, like have a go yourself... They won't tell you straight up, it's more of a figure it out and you'll get there in the end,” (Student 9, Alpine Secondary College). While Coastal Secondary College’s classroom STEM curriculum did not seem to emphasise investigations, the community-based programs had a strong investigation element, with students leading the exploration of, and action on, local issues. It was only at River Valley College that this element of inquiry seemed well established, with students of all ages regularly developing and leading investigations. Interestingly, some participants at some schools expressed
concerns around this element of inquiry-based learning, based on their experience, or lack of experience, in facilitating this form of learning. Leanne spoke about feeling under-prepared to teach in this way, saying “They want me to do that I’m going to have to be taught how to do it, because I don’t know how” (Leanne, Teacher, Sweeping Plains College). Teacher preparation and experience is understood to be a barrier to implementing inquiry-based learning (Clayton et al., 2017; Fitzgerald et al., 2019). Liz reflected on River Valley College’s previous attempts at inquiry-based learning, “There was a bit of a time when we had explore and find it out for yourself sort of classes and the kids didn’t cope very well with that,” (Liz, Numeracy leader, River Valley College). The poor engagement of students in these very open-ended and unstructured classes emphasises the essential role of scaffolding in inquiry learning (Belland et al., 2017).

**Digital technology**

The use of high-end digital technologies is also a commonly recommended element of STEM education (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B), however it was largely absent from three of the four sites. Only participants from Sweeping Plains College emphasised their access to, and use of, digital resources as contributing to its STEM success, with gaming, 3D printing, and Computer Assisted Design all part of the curriculum. Coastal Secondary College also had a good range of digital resources, however the school’s laboratory technician said these were rarely used and suggested this was because the teachers did not know how to use them. In contrast, River Valley College and Alpine Secondary College had few digital technology resources. Participants at River Valley College and Alpine Secondary College expressed concern about their schools’ lack of digital technology resources, however believed they had inadequate finances to remedy the problem. These barriers to the uptake of digital technologies, such as lack of teacher expertise and lack of finances, are well represented in literature (Sanders & George, 2017). Interestingly, one River Valley College participant, Stuart, felt the lack of resources was not a hindrance, arguing that expensive technologies were not necessary for an effective STEM education program.

**External partnerships**

Another commonly recommended STEM education strategy is the formation of partnerships with community groups, tertiary institutions or businesses (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). The STEM successful schools in this study made use of such partnerships in the STEM-related place-based learning programs that ran parallel to their
standard STEM classroom program. Coastal Secondary College’s community-based programs were largely dependent on such partnerships, with students working with VicRoads, the Water-police, Parks and Wildlife rangers, the Desalination plant, and retail businesses in town. Similarly, Sweeping Plains College’s VET programs relied on local businesses and agencies for work placements for their students. Alpine Secondary College staff worked hard to enrich student STEM learning through accessing extra-curricular experiences with universities and STEM industry. Aspects of River Valley College’s STEM-related extra-curricular and careers programs involved working with local groups, including the Country Fire Authority and the Snowy Mountains Hydroelectric Scheme. There is only limited evidence supporting the use of place-based learning for rural STEM education (e.g., Avery, 2013; Clark et al., 2015; Peterson et al., 2015). The perceived positive impact programs based on local partnerships at the schools in this study contributes somewhat to this evidence base.

While each school utilised partnerships to support a variety of STEM-related programs, collaboration with external bodies was less common in the delivery of the prescribed STEM curriculum. There were a few instances of participants citing incursions or excursions contextualising and enriching classroom content, such as airport staff speaking to Physics students at Alpine Secondary College, or long bus-trips to universities to experience the use of technical equipment and investigations. However, these stand-alone instances could not be described as partnerships. Several teachers cited difficulties in forging partnerships with local organisations. Teachers at Sweeping Plains College and River Valley College both commented on a dearth of appropriate local industry or community groups to partner with. Veronica highlighted some other difficulties associated with external partnerships:

If you go to tertiary or into the workplace they have their own language and their own time, scales and they don’t understand how to talk to these students and the timescale … they have lots of flexibility and we’ve got 45 minutes this time or a day. (Veronica, mathematics leader, River Valley College).

Veronica preferred to use her connections with local organisations to facilitate her own professional learning, and to use this to connect student learning to local contexts. Stuart, science leader at River Valley College, said that they rarely partnered with local groups, however he said that the River Valley College STEM teachers themselves engaging
students with “problems out in the community that science and technology can fix” had contributed more to the school’s STEM success. These barriers to forming partnerships and developing place-based learning programs for STEM education are not strongly represented in the literature.

### 7.2.4 Equity

Participants spoke of strategies to deal with the challenges of rurality, and relative low family socio-economic status, though the type and emphasis placed on these strategies varied from site to site. There was an acknowledgement that family budgets struggled to support STEM excursions requiring long, expensive trips. At River Valley College and Coastal Secondary College STEM teachers minimised such trips, emphasising instead visits to (and from) local industries, while Alpine Secondary College staff invested significant energy acquiring additional funding to support trips to Melbourne. Sweeping Plains College participants made little reference to excursions for STEM learning, either near or far, though there was mention of only infrequently hosting incursions due to cost. River Valley College participants also directly addressed issues associated with the relatively low educational backgrounds of their parents. Teachers spoke about offering additional help as they are aware the help is not available at home, for example, “We had kids who are farmer’s kids who – they just didn’t do mathematics… I don’t like that they say, oh, my Mum can’t do mathematics so I can’t do it. We try and break that,” (Veronica, Mathematics leader, River Valley College). These practices seemed designed to mitigate the impact of family socioeconomic status on STEM learning, a factor well understood to impact negatively on both student engagement and achievement in STEM (Belsky et al., 2017; Cooper et al., 2018; Martin et al., 2012).

Beyond managing the impediments of their isolation, schools tended to deal with the rurality of their location through what McCashen (2005) might describe as a strengths-based approach. As described in Section 3.2, strengths-based approaches are used in psychology and social work as a way to facilitate positive change in situations of disadvantage (Bozic, 2013; Saleebey, 2012). The schools in this study all identified and exploited aspects of being rural, belonging to a rural community, and the resources available in the local area, to deliver their STEM education program. The place-based learning experiences frequently employed at Coastal Secondary College, River Valley College and Alpine Secondary College are an example of this, and are a strategy advocated as appropriate for education in rural contexts (CESE, 2013; Hardré et al., 2009). Teachers and students at Coastal Secondary College felt that their use of hands-on learning particularly catered for the learning strengths of their
students. All schools commented on using the positive relationships and close community connections as a way to hold high learning expectations and provide the necessary learning support in STEM.

Other equity issues prominent in the STEM education research literature were not addressed to any great extent by participants. Gender, arguably the most widely known issue in STEM education, with industry groups and policy makers calling for the gender imbalance in STEM careers to be urgently addressed (Australian Industry Group, 2015; Murphy, MacDonald, Danaia, & Wang, 2019), was only mentioned by one participant when reflecting on her own experience of STEM education:

I was the only female out of 200 kids to do mathematics at the higher level. So to be the only female in your classroom is a bit daunting and, and I didn’t like how I was treated by other students … just because I was female. So I definitely knew what I didn’t want my kids to feel like. (Veronica, Mathematics leader, River Valley College)

Issues associated with race or culture and STEM education were not mentioned by any of the participants at any of the schools. This is possibly not surprising given the relatively low proportions of students from a language background other than English - in the range of 1% to 8% (ACARA, 2019), compared to a Victorian School average of 18% (DET Victoria, 2019). However, it is also a potential concern given the proportion of students at these schools identifying at Indigenous Australian or Torres Strait Islander at the sites was generally higher than the average Victorian government secondary school - a range of 1% to 5% compared to 2% across the state (ACARA, 2019). Despite lack of explicit discussion of these significant equity issues in STEM, many of the practices employed at the schools are known to support the learning of students known to be under-represented in further STEM study and STEM careers. For example, using real-life contexts, connecting learning to the local community, and working collaboratively is known to support the engagement of girls, students from low SES backgrounds, and Indigenous students in mathematics (Stacey et al., 2015).

7.2.5 Pathways
All schools credit STEM education practices from Years 7 to 12 with contributing to their STEM success, with the two P-12 schools also highlighting the impact of practices in the late primary school years. The research literature suggests that students tend to disengage from
mathematics through the later years of primary school, with this situation not improving throughout secondary school (Attard, 2013; Larkin & Jorgensen, 2016). The schools had various programs that were felt to support student engagement in mathematics throughout students’ learning journeys. Practices in Years 5 and 6 in mathematics education at both Sweeping Plains College and River Valley College were believed to foster student engagement and motivation. Sweeping Plains College’s differentiated mathematics program, and River Valley College’s integrated STEM program, were described as supporting student autonomy and self-efficacy in mathematics. Coastal Secondary College’s differentiated mathematics program was described by some students as repairing poor self-concept beliefs established in primary school. Students across the schools also spoke about differentiation and opportunities to accelerate in mathematics through Years 9 and 10 as maintaining their engagement in mathematics through to VCE. The structured after-school mathematics support sessions at Coastal Secondary College and River Valley College were attended by students from across the year levels.

Research suggests students disengage from science in the early years of secondary school (Danaia et al., 2013; Goodrum et al., 2012). Participants at three of the four schools -- River Valley College, Alpine Secondary College and Coastal Secondary College -- identified various practices designed to maintain student engagement in science. An emphasis on hands-on learning was described by participants at these schools as contributing to the engagement of all learners in science during the transition to, and throughout the early years of, secondary school. Alpine Secondary College participants valued their science electives as contributing to student interest and self-efficacy in science from Years 8 to 10, allowing students to choose subjects suited to their ability level and interests. All these schools also highlighted the importance of supporting Year 10 students to accelerate into senior science subjects as a way to maintain the engagement of high achieving students.

Maintaining a STEM learning trajectory is dependent on there being a STEM path to follow. Research shows that many schools, particularly those in rural locations, frequently do not maintain a broad range of science, technology and mathematics subject offerings (Murphy, 2018a, 2019a, 2019b). In particular, advanced mathematics (in Victoria, VCE Mathematical Methods and Specialist Mathematics), Physics and Chemistry, the subjects that the national Australian school STEM strategy prioritised for improved participation (Education Council, 2015), are frequently not offered in rural schools. In contrast, the schools in this study maintained a breadth of STEM subjects. In particular, these schools managed to sustain classes in several, if not all, the STEM subjects prioritised in the national strategy.
Participants at several schools credited their careers programs, implemented from early secondary school through to the senior years, with contributing to student motivation in STEM throughout their schooling. Building student STEM career aspirations through enhancing awareness of further study and career opportunities in STEM is a common element in the various Australian STEM strategies (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). The schools, in particular Alpine Secondary College, also provided their students with co-curricular STEM enrichment opportunities, similar to those described in the literature as improving rural student attitudes and aspirations in STEM (Elam et al., 2012; Ihrig et al., 2018).

Finally, a range of other factors, with poor or no representation in the STEM literature, were felt to facilitate student STEM learning journeys at the schools. Participants spoke about the relationships between students of different year levels building the STEM aspirations of younger students. Teachers at many schools spoke about the benefit associated with teaching STEM across multiple year levels. First, they noted it allowed teachers to maintain and develop relationships established with students in junior levels through to senior levels. Second, they suggested that an understanding of the full learning trajectory allowed them to better prepare younger students for study in the senior years of school.

7.2.6 Educator capacities

Australian school STEM strategies all have a significant focus on building STEM teacher capacity (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B), and this focus was shared by each of the schools in this study. Schools worked towards improving STEM teacher capacity through both strategic recruiting to the STEM team and through the professional development of the STEM team.

Schools in the study recruited teachers to their STEM teaching team both externally and internally. River Valley College leaders went to great lengths to hire skilled STEM teachers, finding employment for partners, placing children in school, and adjusting timetables to lure appropriately qualified teachers to the school. Sweeping Plains College’s Principal spoke about recruiting and retraining people from industry to teach technology subjects. These practices were presented as meeting head-on the well understood difficulties associated with recruiting science and mathematics teachers in rural schools (Handal et al., 2013; Weldon, 2016). Each of the schools also staffed some STEM subjects with teachers without appropriate qualifications, similar to many Australian schools (Marginson et al., 2013), and particularly rural schools (Lyons et al., 2006). Where this was done, significant
supports were put in place to support the out-of-field teachers, measures that can be seen as mitigating against the concerns associated with out-of-field science and mathematics teachers (Handal et al., 2013; Weldon, 2016). At Alpine Secondary College, where possible, the out-of-field teacher was placed in a co-teaching arrangement with an experienced STEM teacher, so that they could plan and even teach together. Such co-teaching arrangements have been shown to improve pedagogical practice, as well as facilitate collegial support and professional learning (Lusk et al., 2016, Danaia & Murphy, 2020). At River Valley College and Coastal Secondary College, mentor teachers were formally assigned to support the out-of-field teachers. Participants at both Coastal Secondary College and Sweeping Plains College spoke about engaging out-of-field teachers in significant professional development in STEM education.

The STEM teams at each of the schools also maintained a strong focus on professional learning, employing many of the mechanisms identified as best practice for mathematics professional learning (Watson et al., 2012). The STEM teachers at each of the schools largely drove their own professional learning in response to self- and team-identified priorities. These were generally informed by an in-depth understanding of their students’ needs, and the school context. Professional learning was generally viewed as an ongoing and collaborative process, and was frequently informed by research literature accessed online, through readings, or through some members of the STEM teaching team attending external workshops. Similarly, the mode of professional learning at these schools reflected many of the attributes found effective in STEM professional learning in rural schools. The schools had an emphasis on collaboration, with strong connections existing between teachers within the school, and in Sweeping Plains College’s case, with teachers in neighbouring schools, as has been found effective in rural mathematics professional learning (Goos et al., 2011; Pegg & Panizzon, 2011). Professional learning at the schools was seen as an ongoing process, responsive to local needs, and directed by teacher-identified concerns, as has been found effective in remote schools by Jorgensen (2016).

7.3 Other contributors to school STEM success
There were several practices themes that participants at the schools believed had contributed to their school’s STEM success that are not strongly represented in Australian STEM education policy or in the STEM education literature. These included place-based learning,
differentiated instruction and STEM pathways, and holding high expectations in conjunction with providing generous learning support.

7.3.1 Place-based learning
As demonstrated in the previous section through the repeated references to the contribution of place-based learning, elements of place-based learning align with key elements of effective STEM education. As discussed, it seemed to foster student engagement, through highlighting the utility value of STEM, by tapping into themes that rural students are predisposed to be interested in, and by motivating students through their relationship to place and community. Further, it provides authentic, real-world context for STEM learning, elements advocated for in the STEM education literature. Finally, it often capitalised on local partnerships to enhance STEM learning. While it aligns well with practices promoting in the literature as contributing to STEM learning, place-based learning is not explicitly advocated for in school STEM policies, nor is it strongly represented in the STEM education research literature. Place-based learning is promoted as an effective rural education strategy in Australia (CESE, 2013; Halsey, 2018), however there is scant research into its impact on STEM learning in Australia. In fact, there is limited exploration of the impact of place-based learning on STEM learning in general, and this tends to be associated with rural education and comes from the U.S. (e.g., Avery, 2013; Clark et al., 2015; Peterson et al., 2015). Given the power attributed to these types of programs at the schools in this study, this seems a practice that warrants further research attention.

7.3.2 Differentiated Instruction
Differentiated instruction, particularly in mathematics, was a practice the schools felt contributed significantly to their STEM success, yet this is not a conspicuous theme in the STEM education literature. There is research exploring differentiation in mathematics, however the forms of differentiation are varied and findings around their impacts are inconsistent (Anthony et al., 2019). The form of differentiated instruction adopted at both Sweeping Plains College and Coastal Secondary College is similar to that described by Prast et al. (2015) with its cycle of identifying individual learning needs, setting personalised goals, providing differentiated instruction and practice, and assessment of progress and process. There is only limited evidence that such a model improves student achievement, dependent on its implementation (Prast, Van de Weijer-Bergsma, Kroesbergen, & Van Luit, 2018). In fact, the use of differentiation in general has only a small to medium effect on average
student achievement, and in some circumstances a negative effect on the performance of low-ability students (Deunk, Smale-Jacobse, de Boer, Doolaard, & Bosker, 2018). Interestingly, participants at Sweeping Plains College and Coastal Secondary College schools spoke primarily about the impact of differentiated instruction on student engagement rather than achievement, with differentiated instruction felt to improve student self-efficacy, autonomy, and academic emotions. Similarly, the science electives at Alpine Secondary College were primarily viewed as impacting positively on student interest, autonomy, and emotions. However, there is scant research exploring the impact of differentiation on student engagement. What is apparent in the research are the conditions under which differentiation can be effective, including where teachers have an accurate view of students’ learning needs, and where teachers work in a supportive, collaborative environment where expertise and experience is shared (Deunk et al., 2018). Participants perceived these conditions to have existed at the schools in this study, facilitated by strong relationships between teachers and students and between the teachers themselves.

7.3.3 High expectations with support
Practices that communicate high expectations for learning in STEM education, alongside practices that support improvement in STEM performance for all learners, were cited as significant contributors to each school’s success. Expectations for learning have long been understood to impact student performance (Marzano, 2010), and teacher expectations are well recognised as playing a contributing role in exacerbating equity issues in education related to culture and socioeconomic status (Rubie-Davies & Peterson, 2016; Sorhagen, 2013). Despite this, learning expectations do not feature strongly in the STEM education literature. There is some research evidence that teacher expectations impact student achievement in mathematics (Bohlmann & Weinstein, 2013; Jorgensen, 2016b; Szumski & Karwowski, 2019) but scant literature on its impact in the sciences or technologies or STEM as a whole. Similarly, while teachers’ supportive behaviours are known to impact student engagement (Roorda, Koomen, Spilt, & Oort, 2011), the notion of teacher support and care is not prominent in the STEM education literature. Unsurprisingly then, even less is known about the impact of the practice of establishing high expectations complemented by extensive teacher support on STEM learning, as evident at the schools studied. Sandilos et al. (2017) found that teachers who were caring while also challenging had a significant impact on achievement gain in high-stakes testing that included mathematics assessment. There is some support for such an approach in the non-STEM literature, however this literature is also not
extensive. Liou and Rojas (2016) studied the positive impact of a social studies teacher’s academically rigorous and caring approach when working with marginalised students. An approach of high expectations coupled with strong relationships is promoted as a key element of effective education for Indigenous Australian students (Stronger Smarter Institute Limited, 2014). The approach of high expectations with support touted by participants across the sites in this study as contributing to rural school STEM success seems worthy of further investigation.

7.4 Summary
As demonstrated, some of the elements prominent in the STEM literature are present and appear to have contributed to the relative STEM success of the schools in this study. The importance of student engagement in STEM learning is clearly demonstrated in the literature (Murphy, MacDonald, Wang, & Danaia, 2019) and Australian school STEM strategies acknowledge this, if somewhat vaguely (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). Aligning with this, the schools attributed their efforts to engage students in STEM and STEM learning as one of the most significant contributors to their success. They employed a broad arsenal of strategies to ensure the engagement of all students, impacting a range of motivational factors. In particular strategies that raised task value by highlighting utility or interest, as well as generating positive emotions and minimising negative emotions associated with STEM learning, were employed at the schools. Participants at all schools also felt that relatedness -- to teachers, to peers, and to place -- was a potent motivator and contributor to the STEM success of their schools.

The literature also demonstrates that effective STEM education is cumulative, with engagement and achievement the result of learning experiences throughout schooling. At each school, attention paid to the learning trajectory of each student in STEM, from Year 7 (and in the case of River Valley College and Sweeping Plains College, from Year 5) through to Year 12, seemed to have contributed to high STEM performance. Efforts to engage students were applied across the year levels. Aspiration building and career knowledge in STEM began early. Additional support, particularly in mathematics, was available to, and utilised by, all ages, not just senior students.

Finally, the literature and Australian STEM policy strongly acknowledge the importance of having skilled and confident STEM educators to facilitate effective STEM education. The schools’ leaders wrestled the well-documented difficulties associated with
recruiting STEM teachers to rural areas creatively, using networking, flexible timetabling, and staff re-training when attempting to fill STEM vacancies. Leaders at the schools were also strongly supportive of professional learning, and the professional learning at the schools reflected evidence-based practice for professional learning for STEM educators, particularly those in rural areas.

Other themes associated with effective STEM education in the research literature were not as evident or not seen as significantly contributing to success at the schools in this study. While the importance of developing student STEM capabilities was not overlooked, these capabilities tended to be viewed as discipline bound, rather than interdisciplinary as advocated in the literature. There was, however, good emphasis across the sites on exploring STEM capabilities as they relate to real-world contexts. Much of the STEM education literature suggests that effective STEM education has an integrated structure and takes an inquiry-based learning approach, however participants did not attribute their schools’ STEM performance to these features. While it is arguable that these features were present in the STEM programs at each school to a greater or lesser degree, they certainly did not dominate the STEM education program of the schools, often running parallel to formal STEM classes. Further, while participants at the schools acknowledged the impact of some of the inquiry-based programs on STEM learning, it was most often just in terms of building student engagement, rather than developing all STEM capabilities. Finally, while STEM policy promotes the use of new technologies and collaboration with experts for effective STEM education, the contribution of digital technologies and external partnerships to the school’s STEM success was mixed. Only Sweeping Plains College participants touted their excellent access to technological resources as a contributor, where Alpine Secondary College and River Valley College participants noted their resources were modest. Though all schools made use of partnerships to support some of their STEM related programs, such partnerships rarely contributed to their formal STEM education programs.

While the practices of the schools reflect elements promoted in literature as contributing to effective STEM education to varying degrees, there were prominent practice themes at the schools that have been given little consideration in school STEM policy or the STEM education literature. Place-based learning has relatively limited representation in the STEM literature, however this was a strong feature at the schools studied. The use of differentiated instruction and supporting a variety of STEM learning pathways is similarly relatively underexplored as part of effective STEM education. Finally, while teacher expectations are understood to impact student learning, as is perceived teacher support, the
importance of the two combined, as evident at all four schools, is not strongly represented in the research literature, particularly not in STEM education.
Chapter 8: Key messages, implications and recommendations

8.1 Preamble
This concluding chapter begins by discussing the key messages drawn from the study’s findings. These key messages centre on the demonstrated potential for rural schools to succeed in STEM education, the practices that this study has shown can contribute to this success, and the alignment, or lack thereof, of these practices to those previously promoted in the literature as contributing to effective STEM education. Following this, the implications of these key messages are explored, taking the form of: a set of recommendations for rural schools aiming to improve their STEM education practice, a challenge to policy makers to better consider the challenges and opportunities of STEM education in rural schools, and suggestions for future research.

8.2 Key messages
There are five key messages arising from the findings of this study: Rural schools can succeed in STEM education; bundles of practices are responsible for school STEM success; the practices of STEM successful rural schools only partially align with those prominent in the STEM education literature; some practices promoted as contributing to effective STEM education may not be necessary for rural school STEM success; and some of the practices contributing to rural school STEM success are not prominent in STEM education literature. These key messages are explored in this section.

8.2.1 Rural schools can succeed in STEM education
Phase One of this study found that on average Victorian schools in nonmetropolitan locations underachieved in senior STEM subjects when compared to metropolitan schools. These findings align with previous research exploring the impact of location on Australian students’ science and mathematics achievement, and with similar trends internationally (Thomson, De Bortoli, & Underwood, 2017; Thomson, Wernert, et al., 2017). Phase One also examined the relationship between senior school STEM enrolments and school location, something rarely examined in the published research literature. It was found that nonmetropolitan Victorian schools have lower average enrolment proportions in advanced mathematics, and higher enrolment proportions in entry level mathematics, and design technologies. Enrolment proportions in the sciences and digital technologies were found to be similar in metropolitan
and nonmetropolitan schools. Given the dearth of literature exploring the impact of location on participation in senior STEM studies, the findings of this study concerning enrolment proportions are a new contribution to the field.

While Phase One showed that nonmetropolitan schools had lower average achievement in senior STEM, as well as lower enrolments in advanced mathematics, it also revealed considerable variation in the STEM performance of schools in similar locations and serving families with similar socioeconomic backgrounds, something previously not represented in the research literature. Twenty-five non-metropolitan schools out of the 122 Victorian non-metropolitan schools were found to be relatively high STEM performing, with higher STEM subject enrolments at Year 11 and Year 12, and higher STEM subject achievement, compared with the average nonmetropolitan school from the same SES quartile. Nineteen of these nonmetropolitan schools were found to be located in rural towns rather than regional cities. This demonstrates that rural schools can succeed in STEM education and that this success does not vary considerably annually, but can be sustained for at least three years. This success is despite documented difficulties associated with subject delivery (CESE, 2013; McPhan et al., 2008), staffing (Weldon, 2016), resourcing (Lyons, et al., 2006), and learning expectations (Pegg & Panizzon, 2011). Further, 29 non-metropolitan schools were shown to be below average on all of the above mentioned measures. Demonstrating this variation represents an original contribution to the field, as well as lending strength to the rationale for this project by showing there are high STEM performing rural schools worthy of study to learn about effective STEM education in rural schools, and low STEM performing rural schools that may benefit from the findings of such research.

8.2.2 Practice bundles underpin effective STEM education

Case studies of four high STEM performing rural schools were carried out as part of Phase Two. Participants in all the schools researched in Phase Two attributed their school’s STEM success to a bundle of practices, rather than to a single intervention or measure. The word ‘bundle’ is used here deliberately. Bundle has connotations of a collection of things informally packaged up or tied together. This is the impression given by participants at the high STEM performing schools about how the practices that led to their success were arranged. Rather than being a formal assembly of practices deliberately executed as elements of effective STEM education, the practices were implemented usually concurrently but with little consideration as to how one practice might contribute in relation to, or impact upon, other practices being employed. The practices at each school had been merely bundled
together, interacting with each other, and ultimately contributing to each school’s high STEM performance.

Further, the practice bundles contributing to each school’s STEM success were unique to each site, and shaped by each school’s particular context. However, they were comprised of practices that bore some similarities across the cases. These practices related to setting high expectations for STEM learning and providing generous support, situating STEM learning in real-world contexts, raising the perceived value of STEM, and building STEM teacher capacity. Other practices included variations of using hands-on activities and place-based learning strategies, differentiating instruction to meet student learning needs, and supporting a diversity of STEM learning pathways. These practices influence one and other on a site by site basis, collectively contributing to the STEM success of each school.

Similarly, the practice bundles contributing to each school’s STEM success were shaped by inter-related and overlapping Practice Architectures that shared similarities across the cases. Participants in all four schools felt that their rural location had facilitated effective STEM education through both the material and cultural arrangements associated with rural locales. Teachers made strong use of the resources available due to the surrounding natural environment, as well as the local industries, to enrich STEM learning. There was also a belief that the rural location left students predisposed to be interested in STEM and STEM related careers, contributing to each school’s STEM learning culture. Strong relationships, both within and beyond the school were also felt to facilitate effective STEM learning. Strong teacher-student relationships enabled effective support and personalised learning, teacher-teacher relationships supported effective professional learning, and school-community relationships facilitated place-based learning. Leaders at each school also employed some unconventional timetabling and programming approaches that enabled some of the effective STEM education practices. Further, these school leaders also implemented creative employment and staff development strategies, allowing them to staff their STEM classes with highly capable teachers.

8.2.3 Practices of STEM successful rural schools align somewhat with those prominent in STEM education literature

Some of the practices discussed in the previous section align with strategies advocated within STEM education literature. In particular, there was had a common focus across the schools on improving student engagement with STEM and STEM learning, addressing STEM
learning throughout a student’s learning journey, and building the capacity of STEM teachers; all prominent themes in the STEM education literature.

The importance of student engagement in STEM learning is emphasised in the literature (Murphy, MacDonald, Wang, & Danaia, 2019) and Australian school STEM strategies acknowledge this, if somewhat vaguely (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). Aligning with this, the participants at the schools attributed their efforts to engage students in STEM and STEM learning as one of the most significant contributors to their success. They employed a broad arsenal of strategies to maximise the engagement of all students, including practices such as: high expectations with support, differentiated instruction, hands-on activities, real-world learning contexts, place-based learning, supporting STEM pathways, promoting the value of STEM, and careers education. All the practices believed to have contributed to the schools’ STEM success, other than building STEM teacher capacity, were described as impacting, at least in part, through improving student engagement with STEM learning.

The STEM education literature also promulgates that effective STEM education is cumulative, with engagement and achievement the result of learning experiences throughout schooling (Murphy et al., 2020). The findings of this study support this idea. Each school was attentive to the entire STEM learning journey of their students and believed this to have contributed to their high STEM performance. Efforts to capture student interest in STEM, to demonstrate the relevance of STEM learning, and to build aspirations in STEM began early at each school. Similarly, high expectations for achievement and improvement in STEM subjects were held from the beginning of secondary school, if not before, and these expectations were complemented by generous support throughout each student’s schooling.

Finally, the literature and Australian STEM policy strongly acknowledge the importance of having skilled and confident STEM educators to facilitate effective STEM education (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). The school leaders in this study confronted the well-documented difficulties associated with recruiting and retaining science and mathematics teachers in rural areas (Weldon, 2016) in a variety of ways, including flexible timetabling, re-training experienced non-STEM teachers and experienced non-teacher STEM workers, and working to integrate the partners and families of new teachers into the community. Leaders at all the schools were also strongly supportive of professional learning, and the professional learning that the staff engaged in reflected best practice for mathematics professional learning in rural locations (Goos et al., 2011; Jorgensen, 2016a; Pegg & Panizzon, 2011).
8.2.4 Some practices promoted as contributing to STEM education may not be necessary for STEM success in rural schools.

While some of the practices promoted in the literature as contributing to effective STEM education were regarded as key factors in the STEM success of the rural schools studied, other elements prominent in the STEM education literature were not identified by participants as having played a significant role in the schools’ high STEM performance. STEM education themes conspicuous in the research literature but almost absent from the participant accounts of school STEM success in this research included: the integration of STEM disciplines, the use of inquiry learning, the use of digital technologies, STEM education delivered through school partnerships with industry or community organisations, and directly addressing equity issues in STEM. This is not to suggest that these elements were not present at the high STEM performing schools, but that participants did not credit these elements with their school’s strong STEM performance.

Integration of the STEM disciplines is integral to many definitions of STEM education, and is a prominent theme in the STEM education literature (Bybee, 2013; Murphy, MacDonald, Danaia, & Wang, 2019), yet this practice was rarely explicitly identified as contributing to the schools’ STEM success. There were elements of STEM integration at the schools -- most commonly present in STEM related programs and not the STEM curriculum per se -- however, integration was rarely described as a key element of the practices leading to STEM success. In fact, where integration was discussed by participants at the schools, the limits and difficulties associated with developing integrated programs were often highlighted. STEM integration was present, though not prominent, across the schools studied, but was not seen as a powerful contributor to the schools’ high STEM performance.

Similar to integration, inquiry learning is widely seen as an essential element of STEM education (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B), but, similar to integration, inquiry learning practices were seldom attributed a role in contributing significantly to the STEM success of any school. Key elements of inquiry learning, such as the use of real-world contexts, hands-on learning, and student collaboration (Gee & Wong, 2012) were described as important to the STEM programs at most of the schools. However, the investigation element of inquiry learning, where students choose, design, and direct their own investigations (Gee & Wong, 2012) was not prominent in the STEM programs at any of the schools. Further, there was also reticence expressed about this element by participants at several schools, based either upon past experiences of failure or a lack of teacher knowledge.
and self-efficacy in employing such a pedagogy, reflecting some of the researched impediments to inquiry learning (Fitzgerald et al., 2019).

The use of advanced digital technologies and partnerships with industry or community groups are also recommended as features of effective STEM education (Australian Industry Group, 2017; Murphy, MacDonald, Danaia, & Wang, 2019), however these elements were not strong features across the STEM education programs of the schools studied. Some schools had established partnerships, and these supported STEM related programs, but none of the schools used partnerships to deliver their STEM courses; though local networks were used to access resources to enrich STEM learning. In fact, participants highlighted the impediments to establishing such partnerships, including a lack of appropriate groups to partner with, or an incompatibility between external groups’ capacities and schools’ needs. Similarly, advanced digital technologies were not a strong feature of the STEM education programs at the schools, either due to lack of resources or lack of teacher capability to use the digital resources. Further, at the schools with relatively poor resourcing, participants did not see their lack of extensive digital resources as particularly problematic, suggesting that the resources they had were adequate.

Finally, equity issues associated with STEM education are a prominent theme in the STEM literature. The schools studied were naturally cognisant of the issues associated with rurality, and they also employed mechanisms to mitigate the impact of socioeconomic status on STEM learning. However, there was little attention given to other equity issues commonly encountered in STEM education, such as those associated with female students or students identifying as Aboriginal or Torres Strait Islander. It is worth noting, however, that many of the practices employed at the schools, such as real-world contexts, and collaborative learning connected to local community, have been shown to support the learning of students under-represented in mathematics in tertiary courses and careers (Stacey et al., 2015).

### 8.2.5 Some practices contributing to the STEM success of rural schools are not prominent in the STEM education literature

While the practices at the schools reflect elements promoted as contributing to effective STEM education to varying degrees, there were other prominent practices that have attracted limited attention in school STEM policy or the STEM education literature. Practices that could be categorised as place-based learning were key to the STEM success of these rural schools. Place-based learning aligns well with many factors promoted in the literature as contributing to effective STEM education, including enhanced student motivation through
increased task interest-value and relatedness, and providing authentic and real-world learning contexts. However, there is scant literature describing research into place-based learning in STEM education, particularly in Australian contexts. The emphasis placed on the role of place-based learning practices at the STEM successful rural schools in this study suggests this is a practice that warrants future investigation.

The use of differentiated instruction is also underexplored in the STEM education literature, however this practice in one form or another was viewed as a key contributor to the STEM success of the rural schools in this study. Participants felt that differentiated instruction impacted student engagement, through improved self-concept, autonomy and academic emotions. Research evidence around the impact of differentiation in Mathematics is inconclusive (Anthony et al., 2019) and predominantly focused upon student achievement (Deunk et al., 2018). Certainly, differentiated instruction has no real profile in the STEM education literature. The value participants at the high STEM performing rural schools in this study placed upon differentiated instruction learning flags that this is another practice worthy of further consideration as part of effective STEM education.

Finally, while teacher expectation is understood to impact student learning (Marzano, 2010), as is perceived teacher support (Roorda et al., 2011), the importance of these two factors combined, as evident at all four schools, does not have a strong evidence base, particularly not in STEM education. There is some, but limited, literature suggesting that concurrent high-expectations and teacher support has positive impact when working with marginalised students (Liou & Rojas, 2016; Stronger Smarter Institute Limited, 2014). Other than one published research paper that found such an approach improves student performance in high-stakes mathematics tests (Sandilos et al., 2017), this approach appears to have no representation in the STEM education literature. Given the important role this approach was perceived to play in all four schools’ STEM success in this study, this is another practice that warrants additional research.

**8.3 Implications and recommendations**

The key messages arising from this study have implications, and point to some clear recommendations, for rural schools, policy makers, and STEM education researchers. These findings suggest that rural schools should consider how they can leverage their rural environment, community connections, and relationships to enrich learning in, and enhance student engagement with, STEM education. The findings suggest policy makers need to more specifically consider STEM education needs and opportunities in rural schools. Finally, the
findings make a strong contribution to understanding effective STEM education in an underexplored context where students are known to underperform (rural schools), highlighting opportunities for further investigation, while the study itself models a new approach to expanding our understanding of effective STEM education practices.

8.3.1 Recommendations for rural schools

The findings of this study show that rural schools are able to challenge the dominant narrative of underperformance and poor engagement in STEM education. They demonstrate that there is no one practice, nor uniformly applied set of practices, that lead to rural school STEM success. Rather, STEM successful rural schools implement a bundle of practices that are enabled by site specific factors, including local strengths and opportunities, and respond to the particular needs of their students. The findings show there are common aspects to these practice bundles and Practice Architectures, and these have been used to inform the following recommendations for rural schools.

Use strong relationships to maintain high STEM learning expectations and provide targeted support.

It has been previously noted that rural schools, due to their relatively small communities with low transience, tend to enjoy strong relationships both within and beyond the school (Barley & Beesley, 2007; Halsey, 2018; Hardré et al., 2009; Semke & Sheridan, 2012). This was certainly the case at the high STEM performing schools in this study, with strong teacher-student, teacher-teacher, teacher-parent, and student-student relationships in place. While STEM learning expectations can be relatively low in rural schools (CESE, 2013), these strong relationships provide an opportunity to challenge low expectations and build a culture of high learning expectations in STEM in rural schools. As this study demonstrates, rural teachers can use their positive relationships with their students to set high and achievable expectations for each student. Strong relationships across the staff mean these expectations are consistently maintained, and teacher-parent relationships help to share these expectations with families. Positive student-student relationships, particularly inter-age relationships, can further contribute to maintaining a culture of high expectations, with younger students aspiring to emulate senior students. School leaders can facilitate these relationships by creating both formal and informal opportunities for the STEM team to collaborate and by granting STEM teachers significant autonomy. Similarly, leaders can create opportunities for
students from across the year levels, as well as their parents to be involved in school STEM activities, further enhancing these positive relationships.

Essential to sustaining a culture of high expectations is ensuring these expectations are met. Strong relationships across rural schools can again be used to support this. Strong relationships with the smaller numbers of students at rural schools provide STEM teaching teams with the opportunity to develop a deep understanding of the learning needs, and to track the learning progress, of all their students, so enabling them to provide effective learning support. To capitalise on this opportunity, school leaders need to support the sharing of student data and insights about individual learning needs amongst STEM teachers.

**Capitalise on the local community and environment to enrich STEM learning.**
The use of resources and opportunities available in the local area has been advocated to enrich education in rural schools (CESE, 2013; Halsey, 2018). This study clearly demonstrated that this approach is effective in enriching STEM learning. Rural STEM educators can identify local sites, resources, and issues that can shape and support their STEM education programs. This can go some way to mitigating the noted shortage of STEM resources in rural schools (Lyons et al., 2006). More importantly, this strategy powerfully engages rural students in STEM learning. As noted by participants in this study, rural students have an affinity with outdoors, hands-on, applied learning. Situating STEM learning in local contexts, and conducting projects using familiar resources and at familiar sites, is able to improve students’ self-concept in, and their experience of relatedness to, STEM learning. Further, this strategy helps demonstrate the utility value of STEM, drawing attention to the role STEM plays in familiar and valued industries and activities. School leaders can play an essential role here, developing the networks and connections with local businesses and community groups that allow access to these rich STEM learning resources.

**Establish, maintain, and protect, a breadth of STEM learning pathways, particularly in prerequisite subjects.**
This study highlighted the importance for rural schools of maintaining a wide and flexible breadth of STEM learning pathways. The participants in this study acknowledged the difficulties in doing this, including those associated with staffing and student numbers (Lyons et al., 2006; Weldon, 2016), but despite this, held that this should be a priority. By maintaining a breadth of STEM offerings, rural schools allow their students to build their aspirations in the confidence that their school can support them to meet their goals. Flexible
pathways, including the opportunity for students to accelerate in STEM learning, is motivating, giving students autonomy and avoiding potential negative emotions such as boredom associated with learning stagnation. This study demonstrated that rural school leaders can work creatively, working flexibly with their staff, and potentially other educational institutions, to secure sufficient student enrolments and appropriate staffing, to maintain a breadth of STEM learning pathways.

**Build an autonomous team of STEM staff who drive their own professional learning in response to the needs of their students.**

Rural schools must also have a team of STEM teachers capable of enacting the recommendations described above. Much attention has been paid to the difficulties in rural schools associated with recruiting qualified science and mathematics teachers, and science and mathematics subjects being taught by out-of-field teachers (Handal et al., 2013; Weldon, 2016). The rural schools in this study demonstrated that these difficulties can be somewhat overcome if leaders adopt a less conventional approach to recruitment. Rural school leaders should consider that they are recruiting a STEM teacher and their family, so should be flexible and creative in supporting both teacher and family integrate into the school and local community. Where qualified STEM teachers cannot be found, school leaders can consider recruiting individuals from other industries and re-training them as teachers. Alternatively, where out-of-field teaching is unavoidable, school leadership should select and train experienced teachers to teach STEM. This is counter to the trend of the least experienced teachers being asked to teach science or mathematics out-of-field (Weldon, 2016).

Beyond implementing creative strategies to recruit appropriate STEM teachers, this study also demonstrated the importance of fostering a team of STEM teachers who seek to continually improve their practice. Other writers have argued that effective mathematics and science professional learning must be driven by local demands, such as student learning needs or other teacher-identified issues at their schools, and is most effective when these teachers have established trust and respect, and openly share experiences and expertise (Harmon et al., 2007; Jorgensen, 2016a; Pegg & Panizzon, 2011) and this study certainly supports these arguments. However, the findings of this study emphasise the importance of school leaders supporting the autonomy of rural STEM teachers. Rural STEM teaching teams should be supported to pursue and organise their own professional learning, using online resources, books, or local networks, rather than waiting for an appropriate workshop to be offered in an accessible location. Rural school leaders should work to accommodate and
support STEM teachers in trialing less conventional educational practices in an effort to improve STEM learning, potentially through flexible timetabling. Further, rural school leaders should seek ways to avoid externally imposed requirements, such as slavishly adhering to the scope and sequence of the various disciplinary curricula, impeding rural STEM teachers’ ability to respond to the learning needs and interests of their students.

8.3.2 Implications for school STEM policy
The findings of this study suggest a misalignment between recommendations in Australian STEM strategies, and practices that can contribute to STEM education success in rural schools. The findings do confirm the contribution that can be made to rural school STEM success by practices such as employing real-world learning contexts, and building teacher capacity. However, the schools demonstrated that practices that foster student motivation and positive emotions in STEM are vital for success in their rural contexts, aspects paid only limited attention by the various Australian STEM strategies (Murphy, MacDonald, Danaia, & Wang, 2019, see Appendix B). Further, most of the participants felt that practices making extensive use of digital technologies, or employing partnerships with industry, tertiary, or community bodies, as advocated in Australian jurisdictional strategies, was relatively unimportant to their STEM success. In fact, the findings suggest that these strategies are still impractical for isolated and relatively under-resourced rural schools. Rather, the findings suggest that a flexible, responsive approach to STEM resourcing is important for rural schools, where teachers utilise the resources and learning opportunities available in the local area. Finally, the study revealed practices that may be effective for improving rural school STEM education that are given no attention in any Australian STEM strategies, namely high expectations with support, place-based learning, and differentiated instruction. Given all this, it seems that the recommendations of current Australian STEM strategies may not be the most effective way to improve STEM education in rural schools. Future STEM education policy needs to more carefully consider the practices best suited to rural schools’ contexts, opportunities, and constraints.

8.3.3 Implications for STEM education research
The findings of this study contribute to our understanding of effective STEM education in rural schools, and point to new directions for research in this context. Despite a well understood gap in the STEM achievement of rural students compared to those attending metropolitan schools, rural STEM education has received limited research attention. Hence,
this study makes a contribution to building the evidence base regarding effective STEM education practice in rural schools. Some practices found to contribute to STEM success in the schools studied could be applied in schools independent of location, such as using hands-on activities, and real-world learning contexts. However, some practices seemed particularly facilitated by the schools’ rural locations, relatively small size, and strong relationships across the community. These included practices such as using place-based learning, differentiated learning, and holding high expectations with support. These practices have a limited evidence base in STEM education in general, let alone in rural contexts, so warrant further research. Given that these practices seem to positively harness factors often seen as encumbering rural school success, such as rural location and small size, it is particularly important that they be explored further as a mechanism to help close the gap between rural and metropolitan school performance in STEM.

This study’s conceptual framework and methodology offers a new approach to expanding our understanding of effective STEM education practices. The STEM education research literature is dominated by studies investigating practices already believed to contribute to effective STEM education. These studies presuppose the elements required for STEM success. These studies either investigate sites already implementing particular practices, such as integrated STEM or inquiry learning, or they experimentally investigate interventions built around these practices. This prevailing approach to STEM research deepens our understanding of these proven practices, but risks overlooking practices that may also have the potential to contribute to STEM success. This study’s approach sought to research schools experiencing outcomes associated with STEM success, thus avoiding assuming that any particular practices lead to STEM success. In doing so, it found confirmatory evidence regarding practices well represented in literature. However, it also revealed practices that have previously attracted little attention in the STEM education research literature, such as place-based learning, differentiated instruction, and maintaining high expectations with support, that have the potential to contribute to effective STEM education in rural contexts. These findings support the adoption of this study’s approach in other research as a mechanism to expand our understanding of effective STEM education in particular contexts.

8.4 Summary of limitations and opportunities for further research
There are a range of limitations associated with this project, and these also point to opportunities for further research. As previously discussed, there are limitations associated
with the measures of STEM success employed in Phase One to identify high STEM performing rural schools, referred to in this study as the School STEM Success Criteria. While the School STEM Success Criteria have arguable content validity, as demonstrated in Section 4.4.1, they are dependent upon data available from the DET Victoria. Unfortunately, these data are limited to only giving insight into the performance of students who enrol in VCE (senior) STEM subjects based on largely standardised, discipline-based assessments. Consequently, the School STEM Success Criteria use a measure of STEM achievement that is not applied to all students, is not interdisciplinary, and may not provide strong insight into the development of STEM skills such as critical thinking, creativity, or complex problem solving. Thus, the schools identified in this study as high STEM performing, using these criteria, are those that may merely attract a high proportion of their students to enrol in STEM subjects, which they then perform relatively well in based on a limited assessment schedule. It is possible that they may not be the schools most effective at developing student capabilities associated with interdisciplinary and inquiry oriented STEM often described as desirable in the STEM education literature (Murphy et al., 2020, see Appendix A). Future studies similar to this one could identify high STEM performing schools using alternative criteria, perhaps by employing elements of the STEM Education Data Dashboard recommended by the Education Council (2018), or by employing other assessment tools and data that more directly measure the inquiry skills, interdisciplinary STEM knowledge, and STEM engagement of all students. Similarly, alternate criteria could be developed to identify schools with STEM education programs that more effectively prepare students for success in advanced mathematics, physics and chemistry, or more effectively address other known equity issues associated with the STEM education of girls or Indigenous students.

The design of Phase Two also has limitations worth noting. The case study methodology employed was heavily dependent upon the views of the principals, STEM teachers and students at these schools, cross-checked against key school documents and a one or two day visit to each school. While the method has sound validity and reliability as discussed in section 4.5.4, there is the potential that some factors contributing to school STEM success may be overlooked, particularly if they are regarded as unremarkable by participants. An illustration of this may be the significant time allocated to mathematics education at two of the schools, well above the Australian average, that was not commented upon by any of the participants. Nor was the reduced time that must have been allocated to other subjects at these schools commented upon. Similarly, participants did not comment on the possible impact of the state curriculum or jurisdictional assessment practices on school
STEM success. Future similar case studies may be enriched through more extensive site visits that include observations of teaching and learning, and interviews with non-STEM teachers and students’ parents.

Further, this project did not include study of relatively low STEM performing rural schools. Though the participants attributed their schools’ STEM success to the practice themes revealed through this study, and though these practices showed some alignment to those prominent in the STEM education literature, it is possible that the schools’ STEM success may not be due to these factors. Comparison to similar schools not experiencing the same level of STEM success would provide an opportunity to verify the impact of the practices identified in this study. If the same practices were observed in less well performing schools, the importance of these as elements of effective rural school STEM education would be called into question.

Finally, this study investigated only four relatively high STEM performing rural Victorian schools. STEM education practices, like all school practices, are comprised of a complex collection of situated activities, and the cultural, social, and material arrangements that influence them (Kemmis, 2008). While several common practice themes and Practice Architectures were identified as contributing to the STEM success of all these schools, there were variants in these practices and enabling factors unique to each site. Further case studies in other rural locations, particularly non-Victorian locations, would further test the validity and generalisability of the recommendations and conclusions drawn from this study.

8.5 Summary
This chapter discussed key messages drawn from the findings of this study. Despite a general trend showing that rural schools underperform in STEM education, Phase One of this study demonstrates that some rural schools attract relatively high enrolments, and achieve at higher levels, in senior STEM subjects. The STEM success of four of these schools, investigated in Phase Two of this study, was attributed to a bundle of practices, rather than any particular interventions. Some of these practices were already well represented in the STEM education literature, such as those associated with fostering student engagement, attending to STEM learning throughout schooling, and developing STEM teacher capacity. Others were relatively unrepresented in STEM education literature, including maximising place-based learning, differentiated instruction, and high expectations with support.
There are implications of this work for rural schools, policy makers, and researchers. There are four recommendations based on this study’s findings for rural schools aiming to deliver effective STEM education:

- Use strong relationships to maintain high STEM learning expectations and provide targeted support.
- Capitalise on the local community and environment to enrich STEM learning.
- Establish, maintain, and protect, a breadth of STEM learning pathways, particularly in the subjects that are prerequisites for tertiary STEM courses.
- Build an autonomous team of STEM staff who drive their own professional learning in response to the needs of their students.

Policy makers are called upon to address the misalignment between school STEM strategies and what this study demonstrated is effective and achievable in rural schools. Finally, a range of opportunities for future research are suggested as a result of this study. Some of these are associated with the under-researched practices this study suggests contribute to relative rural school STEM success. Others are associated with addressing some of the limitations associated with this study, including developing alternate ways of identifying STEM successful schools, conducting a more thorough investigation of practices contributing to school STEM success than was possible within the bounds of this study, and exploring the practices of schools that are relatively unsuccessful in STEM education.
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Appendices

Appendix A. Murphy, MacDonald, & Danaia (2020)

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

Steve Murphy¹, Amy MacDonald² and Lena Danaia³

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

2.1 Introduction

There is strong political, industrial, social and educational support for STEM education (Shahan, Burke, & Francis, 2016), however there is no common understanding as to what constitutes effective STEM education. Cognitive aspects of STEM education have received significant attention. STEM education is commonly viewed as interdisciplinary, (Becker & Park, 2011; Honey, Pearson, & Schweingruber, 2014; Yildirim, 2018) with the type and extent of integration being contested (Bybee, 2013; Kelley, 2010; Moore et al., 2014). Other writers concentrate on STEM education for developing complex skills such as problem solving (Bybee, 2013; MacDonald, 2015), data modelling (English, 2016), design processes (English, King, & Smeed, 2017), and spatial reasoning (Lowrie, Downes, & Leonard, 2018). Some researchers advocate particular pedagogical approaches to nurture these capabilities, such as inquiry learning (Gee & Wong, 2012; Von Secker, 2002), problem-based learning (Asunda, 2014), and project-based learning (Caprano & Slough, 2013).

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

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

2.2 Existing Models of STEM Education

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

Zollman (2012) presents a model of STEM literacy based upon Bloom's cognitive, affective and psychomotor learning theory domains. Zollman argues that STEM is a metadiscipline "based on the integration of other disciplines into a new whole" (p. 13) and that there should be "reduced concern for covering content and an increased emphasis in helping a student learn". Beyond this there is no treatment of the acquisition or management of STEM knowledge. Zollman's view is that a STEM literate student needs to have the psychomotor skills to operate STEM technology, value and have confidence in STEM, and apply knowledge to meet their goals. Zollman draws on well-established theorists such as Piaget and Erikson but offers little contemporary STEM education research to support the STEM literacy model. Unlike other STEM education models, Zollman treats the development of physical skills required for STEM separately, and acknowledges that psychomotor
demands change quickly as technologies evolve. In Zollman’s description of STEM literacy there is no reference to STEM across the learning trajectory, or to equity issues in STEM education.

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

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

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

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

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

2.3 Sustaining STEM – A Conceptual Framework for Effective STEM Education

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

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

2.3.1 STEM Knowledge

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

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

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

2.3.2 STEM Skills

STEM capable individuals have the skills to pose, ponder, and solve STEM-related problems that are real and authentic to their personal worlds. Industry and governments call for STEM education to equip students with “STEM skills” with little guidance as to what these skills may be (for example, Australian Industry Group [AIG], 2015; CEDEFOP, 2014; Morgan & Kirby, 2016). Some authors have used employer surveys to identify extensive lists of STEM skills required by STEM industries (for example, Jang, 2016; Prinsley & Baranyi, 2015). Others have aimed for a more manageable set of STEM skills by drawing the 21st-Century skills (for example, Bybee, 2013). Many researchers focus on the skills associated with complex problem solving and the STEM processes implemented to innovate and solve problems (for example, Asunda, 2014; English et al., 2017).

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

2.3.3 STEM Engagement

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

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

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

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

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

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

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

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

2.3.5 STEM for All Learners

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

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

2.4 STEM Practices, Educators, Learning Environments and Leaders

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

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

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

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

2.4.2 STEM Educators

Educators themselves need to be STEM capable, as well as possess additional characteristics that allow them to foster STEM knowledge, skills and engagement in their students through appropriate educational practices. Educators draw on a range of learning theories to inform their practice (Starkey, 2012). The STEM capable educator draws primarily on three related learning theories: personal constructivism, social constructivism (Skamp & Preston, 2018) and connectivism (Starkey, 2012). Personal constructivism sees individuals building understanding through interaction with the material environment. (Skamp & Preston, 2018).
Social constructivism sees learning driven by communication with others and interaction with the social environment. Connectivism sees technology extending interactions beyond the immediate physical environment, and knowledge creation involving making connections between people and information sources (Starkey, 2012). Connectivism views knowledge as unstable, with new understandings evolving and others being superseded or becoming redundant. Between them, these learning theories underpin the Sustaining STEM framework, positioning knowledge as uncertain and socially constructed, STEM skills as developed through interaction with the real world, and engagement fostered through authentic learning activities and social relationships.

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

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

### 2.4.3 STEM Learning Environments

The learning environment, both within and beyond schools and learning centres, contributes strongly to developing STEM capable learners, facilitating STEM education practices and supporting STEM educators. STEM education practices can be supported through policy, resourcing and networking. STEM practices, such as IBL, PBL and PjBL, can be facilitated by access to low-cost and recycled materials in the classroom (Lee, 2014; Liewellyn, Pray, De Rose, & Orman, 2018), and by establishing resource rich environments, such as maker spaces (Sheffield, Kool, Blackley, & Maynard, 2017). Some schools have adopted school wide approaches to problem-solving (Heffy, 2015; Marshall, McGee, McLaren, & Veal, 2011; McCarthy & Slater, 2016; Morrison et al., 2015). In secondary schools, STEM learning and engagement is enhanced through resources and connections beyond the classroom, through projects aiming to contribute to the local community, or make a positive impact on real world issues (Dixon & Brown, 2012; Kelley et al., 2010; Knezek et al., 2013).
Partnerships between primary and secondary school, and community groups, industries, or universities have also been found to support STEM education, either through improved student engagement or by providing expert knowledge and skills (for example, Ardiso et al., 2014; English et al., 2017; McDonald & Howell, 2012).

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

2.4.4 STEM Leaders

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

2.5 Conclusion

By drawing on extensive contemporary literature and providing a structure to address the STEM education needs of all learners at all stages of learning, the Sustaining STEM framework provides a unique structure for investigating and describing effective STEM education. The framework presents a triad of equal and interacting domains: knowledge, skills, and engagement. It views STEM knowledge as unstable, evolving, and created collaboratively, encouraging a focus on ways of knowing, rather than what is known. STEM skills are those associated with the complex, iteritive processes of STEM, and include creativity, critical thinking, and problem solving skills. The framework emphasises the importance of STEM engagement, drawing on constructs of motivation and academic emotions found to impact on STEM learning. These three domains allow for the effective exploration of STEM education for all learners, of different genders, cultures and social backgrounds, from early childhood through to secondary school and beyond.
The Sustaining STEM framework supports the examination and development of educational practice. To become STEM capable, learners need to be provided with opportunities to pose, ponder, and solve problems relevant to their worlds, by working with others and utilising the STEM disciplines. Pedagogies such as PBL, PjBL, IBL and design tasks have the potential to provide such opportunities and to foster engagement with STEM. Educators need beliefs, skills and dispositions appropriate to developing the three domains in their students. They need to believe all students, at all stages of learning, are capable of engaging with STEM learning, and they themselves need the skills to support learner-centred, problem-based pedagogies. Finally, STEM leaders need to work with educators to develop rich learning environments that facilitate these pedagogies, particularly providing opportunities for authentic learning experiences for their students.

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

References


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An analysis of Australian STEM education strategies

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Abstract
In December 2015 the Australian state and territory governments endorsed the ‘National STEM School Education Strategy 2016–2026’. Since then, the individual jurisdictions have released their own STEM education strategies that aim to improve student STEM capabilities and aspirations. This paper analyses the various Australian STEM education strategies in relation to six themes informed by research into effective STEM education: STEM capabilities; STEM dispositions; STEM educational practices; Equity; Trajectories; and Educator capacities. The analysis shows that Australia’s STEM education strategies focus on actions aimed at building student STEM capabilities, particularly through inquiry and problem-based learning, and enhancing educator capacity. The strategies recognise student STEM learning trajectories and pay particular attention to the importance of early childhood STEM education, as well as the ways in which students’ potential career pathways might be influenced. However, less emphasis is placed on supporting key transitions in STEM education, developing student STEM dispositions, and addressing equity issues in STEM.

Keywords
STEM education, early childhood, primary, secondary, educational practice, policy analysis

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Introduction

Building a Science, Technology, Engineering and Mathematics (STEM) skilled workforce and cultivating a STEM literate citizenry has been a focus of governments across the world for at least a decade (Gough, 2015). STEM education, a term that rose to prominence in the late 2000s referring to formal and informal education programmes from pre-school to tertiary level (Shanahan et al., 2016), is seen as the key strategy for achieving these goals. Governments look to STEM education to address an array of local, national and global issues (Gough, 2015). The Incheon Declaration for Education 2030 recommends the strengthening of STEM education as a key strategy for meeting its sustainable development goals (UNESCO, 2015). Fensham (2008), in his report to UNESCO, argues quality science and technology education is essential for socially and environmentally sustainable development by ensuring the supply of scientifically and technologically skilled professionals to drive it, and the preparation of a scientifically and technologically informed citizenry to guide it. STEM education is seen as a vehicle for improving a nation’s global competitiveness and ensuring its economic future (Breiner et al., 2012).

STEM education aims to grow in students the capability and inclination to identify questions and solve problems associated with STEM-related issues and the natural and designed world (Bybee, 2013). Informed by the work of Bybee, this paper takes the stance that effective STEM education explores significant 21st-century challenges in contexts such as health, environment, energy, technology and natural resources. It builds knowledge of the characteristics of the STEM disciplines, as well as an understanding of how these disciplines shape our physical and cultural worlds. Beyond disciplinary skills and knowledge, STEM education builds intra-disciplinary skills, such as complex problem solving, critical thinking and creativity.

While STEM education has been pursued internationally since the mid-2000s, Australia is a relative late adopter (Blackley and Howell, 2015). The Australian STEM education movement has gained significant momentum since 2013 with the publication of several key papers by the Australian Office of the Chief Scientist (2013, 2014) and the Australian Industry Group (2013, 2015). These papers suggest that improving Australia’s STEM education is vital for Australians to effectively manage the changing environment, their health and wellbeing, their food, water and energy, their security, and their economy. There is an accepted correlation between strong performing education systems and nations with thriving economies (Margrison et al., 2013). Given this, the urgency to improve STEM education in Australia is increased by sliding performance of Australian students, both relative to other nations and, in some cases, in absolute terms (Thomson et al., 2016; Thomson et al., 2016). Not only are Australian students underperforming in STEM testing, but fewer of them are choosing to study STEM subjects (Goodrum et al., 2012; McPhee et al., 2008; Morrison et al., 2015). These factors have caused STEM education to become a national priority.

The Australian focus on STEM education saw the state and territory governments endorsing the ‘National STEM School Education Strategy 2016–2026’ in December of 2015 (Education Council, 2015). Since then, different states and territories have released their own STEM education strategies that aim to improve student STEM capabilities and aspirations. Ideally, these strategies would reflect the best evidence available about effective STEM education. This paper analyses the extent to which the various Australian STEM education strategies align to the STEM education research literature. It interrogates the
ways in which the strategies conceptualise ‘STEM education’, the rationales provided by the strategies for the need to improve STEM education, and the types of actions that are recommended by the strategies to improve STEM education. In doing so, it provides insight into the degree to which the STEM education path being adopted by Australian jurisdictions is supported by the available research evidence.

**Literature review**

STEM education research is a relatively young field with limited but growing empirical research available to inform policy and practice (Brown, 2012). Given this, this literature review draws both on scholarly literature and reports from industry and governments. The literature on effective STEM education can be considered in relation to a number of themes. There is a body of literature exploring the impact of STEM education on students, particularly on the development of STEM capabilities, and on nurturing positive STEM dispositions. Other literature examines the delivery of STEM education and explores effective STEM education practices, equity issues in STEM education, or STEM trajectories. There is also a significant body of STEM education research examining the capacity of STEM educators. The following brief literature review brings together the pertinent findings related to these themes in order to offer a framework for analysing Australia’s STEM education strategies.

**Capabilities**

The literature discusses the need for students to develop STEM knowledge and skills to be adequately equipped for their futures and to meet the developing needs of Australia’s industries (Australian Industry Group, 2013). These capabilities include, but are more extensive than, the knowledge and skills associated with the individual STEM disciplines. In a rapidly changing world, STEM knowledge cannot be conceived as stable content; rather, STEM education needs to equip students to source, interpret and apply understandings as they evolve (Roth and Van Eijck, 2010). Similarly, the skill set required by students for life in the 21st century cannot be reduced to a definitive list; however, some skills are known and must be made explicit and included in each child’s education (Marzano and Heflebower, 2012). Bybee (2013) draws on the work of the Partnership for 21st Century Learning and the National Research Council of America to suggest a STEM skill set that includes adaptability, non-routine problem solving, and systems thinking, as well as complex communication skills and self-development. Australian employers seek to employ STEM graduates as they have skills such as active learning, complex problem-solving, creative problem solving, critical thinking, design thinking, programming, and systems analysis and evaluation (Prinsley and Baranyai, 2015). Commonly, the literature suggests that these capabilities are best developed through STEM education practices that use real world contexts and present learners with authentic problems or projects to work upon (e.g. Hefty, 2015; Kelley et al., 2010; Redmond et al., 2011).

**Dispositions**

STEM dispositions are the attitudes and states of mind that support students achieving success in STEM education and the pursuit of STEM career pathways. The research literature highlights the role of affect in effective STEM education and advocates for favourable
dispositions to be cultivated in students. Students need to be interested in STEM, have a positive self-perception of themselves as STEM students, and to see STEM industries as personally relevant, if they are to engage in STEM learning and aspire to STEM careers (Goodrum et al., 2012; OECD Global Science Forum, 2006; Panizzon and Westwell, 2009). There is a significant body of research exploring motivational and academic emotion theory as it related to student STEM participation and performance. This research suggests that STEM self-concept, the value the learner places on STEM and STEM education, learner autonomy, and educator-learner and learner-learner relationships, are some of the most powerful influences on learner motivation in STEM education (e.g. Andersen and Chen, 2016; Petersen and Hyde, 2017; Robnett and Leaper, 2013; Wang and Degol, 2013). Moreover, children’s STEM dispositions can be influenced by educators from the early years onwards (Patrick et al., 2009). Given this, teacher practice, curriculum, and pedagogical choices impact significantly on student STEM dispositions (Panizzon and Westwell, 2009; McPhan et al., 2008).

**Educational practices**

STEM educational practices are intentional actions that schools and educators take to create STEM learning environments that build student STEM capabilities and nurture STEM dispositions. There is evidence that effective STEM education programmes view knowledge as interdisciplinary and present the curriculum in an integrated way (Becker and Park, 2011; Honey et al., 2014; Yildirim, 2016). There is, however, debate around the degree and form of integration of the disciplines in a STEM education programme for best impact on student learning (e.g. Bybee, 2013; Kelley, 2010; Moore and Smith, 2014). It is also clear in the literature that real world inquiry or problem-based learning (PBL) approaches have a positive impact on student learning in STEM education (Gee and Wong, 2012; MacLeod, 2013; McDonald, 2016; Ralph, 2015). At the core of an inquiry approach is the idea that approaches and methods used by STEM professionals should be reflected in the classroom (Gee and Wong, 2012). Such an approach requires that students exercise STEM capabilities (Capraro and Slough, 2013), while also presenting STEM as relevant to students, with the potential to cultivate STEM dispositions (Rennie et al., 2012). Research shows that there is significant variation in the impact of various inquiry approaches on students of different gender, ethnicity and socio-economic status (Gee and Wong, 2012; Von Seeker, 2002). However, there is generally sound evidence to support a real-world inquiry or PBL approach to STEM education.

There is also a call for the increased use of computers and robotics in STEM education. Research shows that the use of these digital technologies expands available learning contexts (Starkey, 2012) and facilitates the development of problem solving and higher order thinking skills (McDonald, 2016). There is also evidence to suggest that digital learning has a positive impact on STEM dispositions, improving student interest and motivation in STEM (Lai Poh et al., 2016; McDonald, 2016; Starkey, 2012).

**Equity**

Research points to a need for STEM education to address significant equity issues for female, rural, Indigenous, and socio-economically disadvantaged students in Australia. Though girls are achieving as strongly in STEM as boys (Thomson et al., 2016), they are
opting out of STEM subjects at a greater rate and are significantly under-represented in some STEM dominated industries (Australian Industry Group, 2013; Marginson, 2013). International and national testing suggests that metropolitan students are around 12–18 months ahead of rural students in both mathematical and scientific literacy, and that this gap is widening (Australian Curriculum Assessment and Reporting Authority, 2016; Connolly, 2017; Thomson et al., 2016; Thomson, et al., 2016). The same testing reveals an even wider gap between the achievement of an average Australian student and that of an Indigenous Australian student in STEM skill development. This testing also suggests a strong correlation between the income and education levels of a child’s family and their development of mathematical and scientific literacy. The literature also suggests that educator curricular and pedagogical choices can have a significant impact on the dispositions and academic success of these different groups (Gee and Wong, 2012; Marginson, 2013; Patrick et al., 2009; Stacey et al., 2015).

Trajectories
An education trajectory can be considered as a long-term view of a student’s educational course or movement through the education system (Elder, 1985; Pallas, 2003). Given this, a student’s STEM trajectory is taken to include their STEM learning journey from early childhood through to senior secondary school and beyond. A growing body of research demonstrates the importance of early STEM competencies for later outcomes in STEM subjects (Johnston, 2011; Watts et al., 2014). However, a number of factors may alter children’s long-term STEM achievement trajectories, including changes in motivation and classroom practices, and failure or success in attaining key skills during the schooling years (Watts et al., 2014). Indeed, a study of children’s early mathematical competencies and later mathematical achievement shows that, while early competencies assist children in ‘getting off to a good start’, the quality of mathematics education experienced in the schooling years is critical (MacDonald and Carnmichael, 2017). Moreover, transitions from preschool to primary, and from primary to secondary, may impact children’s engagement with STEM education (Perry et al., 2015; Tytler et al., 2008). Researchers recommend that effective STEM education occur before secondary school (Tytler et al., 2008), and preferably from the preschool years (Moonaw and Davis, 2010; Milford and Tippet, 2015). Furthermore, effective STEM education throughout the schooling years positively influences students’ aspirations in relation to tertiary STEM study and STEM career pursuits (van Tuilj and van der Molen, 2016).

Educator capacities
In order to meet the demands for delivering integrated, inquiry-driven STEM education that develops in all children the necessary STEM capabilities and dispositions, highly skilled educators are required at all levels of the educational journey. Educators play a pivotal role in STEM education when they provide a safe and supportive learning environment, engagement in effective pedagogical practices, and adequate time to engage in the learning process (McDonald, 2016). However, a number of challenges exist across the STEM educational continuum. Australian secondary schools are struggling to staff Science and Mathematics classes with qualified teachers, with large proportions of these classes taught by teachers without teacher training in these disciplines (Marginson et al., 2013; Prinsley and Johnston
(2015) identify that primary teachers, in particular, make a serious difference in STEM education. However, there is a shortage of primary school teachers that are confident and competent in teaching science and mathematics (Marginson et al., 2013). Similar challenges are found in the early childhood education sector, with many early childhood educators reluctant to engage in intentional teaching of mathematics, science, and technology (Lee and Ginsburg, 2009). On a positive note, research shows that professional development can deepen both the subject and pedagogical knowledge of educators, leading to changes in classroom practice and improved student achievement (Perry and MacDonald, 2015; McDonald, 2016; Reimers et al., 2015).

Method

STEM education strategies, where they existed, were acquired for each Australian jurisdiction. A jurisdiction’s STEM education strategy was regarded as a public document or documents comprising:

- A description of STEM education;
- A rationale for planning to improve STEM education; and
- Recommended actions to improve STEM education.

A web search was used to locate STEM education strategy documents where possible, as this was felt to be the most likely strategy to be used by STEM education practitioners and other audiences for these strategies. Where a search did not yield an obvious STEM education strategy document, the jurisdiction’s education department was contacted directly, to ascertain if a document existed and to request a copy. All jurisdictions provided a response to the query. This resulted in the set of STEM education strategy documents presented in Table 1.

Analysis

This study utilised a thematic analysis approach (Joffe, 2011) to synthesise and analyse the content of the strategies. Each of the Australian STEM strategies were analysed according to their conceptualisation of ‘STEM education’, rationale for developing a STEM education strategy, and actions they articulated to enhance STEM education during the target period of each strategy. Relevant text from each of the strategies was extracted for thematic analysis. Each of the strategies provided a description of how they conceptualised STEM education in their jurisdiction. All strategies also included a section offering a rationale for focusing efforts and resources on improving STEM education. ‘Actions’ were taken to be the specific measures, initiatives, and programmes to be implemented by each jurisdiction that are designed to have positive impact upon learners, learning environments, and/or educators. The STEM conceptions, rationales and actions were interrogated in relation to the research questions using a coding scheme developed from the six themes associated with STEM education presented in the literature review. The key words coded to each of the themes are shown in Table 2.

The first two authors independently coded the relevant sections of the strategy, then held a consensus meeting, discussing coding decisions and developing a consensus view of findings (Hunt and Walsh, 2011).
Table 1. STEM education strategy documents by jurisdiction

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Author</th>
<th>Year</th>
<th>Length</th>
<th>Title</th>
<th>Acquired through...</th>
</tr>
</thead>
<tbody>
<tr>
<td>National</td>
<td>Education Council</td>
<td>2015</td>
<td>12 pages</td>
<td>National STEM School Education Strategy</td>
<td>Web search</td>
</tr>
<tr>
<td>ACT</td>
<td>Education Directorate</td>
<td>-</td>
<td>-</td>
<td>Using the National strategy</td>
<td>Response to request</td>
</tr>
<tr>
<td>NSW</td>
<td>Department of Education</td>
<td>2017</td>
<td>Website</td>
<td>STEM</td>
<td>Web search and response to request</td>
</tr>
<tr>
<td>NT</td>
<td>Department of Education</td>
<td>-</td>
<td>-</td>
<td>Strategy awaiting approval</td>
<td>Response to request</td>
</tr>
<tr>
<td>QLD</td>
<td>Department of Education and Training</td>
<td>2016</td>
<td>2 pages</td>
<td>A strategy for STEM in Queensland state schools</td>
<td>Web search</td>
</tr>
<tr>
<td>SA</td>
<td>Department for Education and Child Development</td>
<td>2016</td>
<td>12 pages</td>
<td>STEM Learning Strategy for DECD Preschool to Year 12</td>
<td>Web search</td>
</tr>
<tr>
<td>TAS</td>
<td>Department of Education</td>
<td>2017</td>
<td>1 page</td>
<td>STEM Framework</td>
<td>Response to request</td>
</tr>
<tr>
<td>VIC</td>
<td>Department of Education and Training</td>
<td>2016</td>
<td>24 pages</td>
<td>STEM in the Education State</td>
<td>Web search</td>
</tr>
<tr>
<td>WA</td>
<td>Department of Education</td>
<td>2016</td>
<td>19 pages</td>
<td>STEM Support Plan 2016/17</td>
<td>Response to request</td>
</tr>
</tbody>
</table>

STEM: Science, Technology, Engineering, Mathematics; ACT: Australian Capital Territory; NSW: New South Wales; NT: Northern Territory; QLD: Queensland; SA: South Australia; TAS: Tasmania; VIC: Victoria; WA: Western Australia.

Results and discussion

The following discussion presents the result of the thematic analysis with respect to the six themes, reflecting on the alignment of the strategies to the STEM education literature, and the consistency between the way Australian STEM education is conceived (as presented in Table 3) and rationalised, and the actions proposed to advance it. It is important to note when reading this analysis that the various strategies varied greatly in style and length, ranging from Tasmania’s single page ‘STEM framework’, through to Victoria’s 24-page overview of STEM education in the State.

Capabilities

As shown in Table 3, student STEM capabilities is a key element of the way each of the Australian strategies conceive of STEM education. Understandably, STEM discipline knowledge and skills are prioritised among the strategies. However, the interdisciplinary capabilities of problem solving, critical analysis, and creative thinking are even more prominent. Capabilities associated with collaboration and digital technologies are also evident, though with less consistency across the strategies. Furthermore, individually the strategies
Table 2. Coding themes and associated key words

<table>
<thead>
<tr>
<th>Theme</th>
<th>Key words</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capabilities</td>
<td>Skills, knowledge, thinking, critical thinking, creativity, problem solving, coding, digital literacy, ICT skills, collaboration, communication, self-direction, investigating, experimenting, hypothesising, numeracy</td>
</tr>
<tr>
<td>Dispositions</td>
<td>Engage, motivate, aspire, inspired, confidence, curiosity, resilience, mind-set</td>
</tr>
<tr>
<td>Educational practices</td>
<td>Inquiry, project-based learning, PBL, real-world pedagogy, authentic, integrated, interdisciplinary, partnerships, networks, links with industry and universities, assessment, digital learning, ICT curriculum, coding, robotics, camps, competitions or challenges, virtual academies, resources, infrastructure, facilities, software</td>
</tr>
<tr>
<td>Equity</td>
<td>All learners, every student, girls, Indigenous and Torres Strait Islander, disadvantage</td>
</tr>
<tr>
<td>Trajectories</td>
<td>Early childhood, transition, primary, secondary, career pathways, lifelong learning</td>
</tr>
<tr>
<td>Educator capacities</td>
<td>Professional development or learning, teacher training, specialist STEM teachers, exemplars, mentoring, high quality STEM teaching, inspirational STEM teachers, preservice STEM teachers, STEM leaders, school leaders</td>
</tr>
</tbody>
</table>

ICT: Information and Communications technology; PBL: Problem-based learning; STEM: Science, Technology, Engineering, Mathematics.

*The key words listed here were taken to include any words that may have the key word as their root (e.g. ‘motivate’ includes ‘motivating’, ‘motivated’, and ‘motivation’).

present a range of other capabilities which are important for STEM, such as communication, interdisciplinary thinking, independent thinking, and inquiry skills.

The need to improve the STEM capabilities of Australians was a strong theme in the rationales of all the strategies. In all but the Tasmanian rationale, the emphasis on STEM capabilities is associated with the need to prepare STEM skilled workers to take up positions in the growing STEM sector, and to ensure a globally competitive economy. Some rationales also speak more generally of the need for improved STEM capabilities in response to a rapidly changing world (QLD, VIC). Less frequently mentioned is the role STEM capabilities play in ensuring individuals lead fulfilling lives as positive community members (TAS, WA). Several strategies cite Australian students’ slide in STEM enrolments and international testing of STEM skills and knowledge as a reason to address STEM education in Australia (National, SA, QLD, VIC).

The strategies adopt a range of actions to improve student STEM capabilities. Three strategies include actions to improve the tools to describe and track the development of STEM capabilities (National, TAS, WA). Despite creativity, critical thinking and problem solving being integral to each strategies description of STEM education few had explicit actions aimed at building these capabilities. Three strategies had actions for problem solving (National, QLD, VIC), three for creativity (National, QLD, WA) and three for critical thinking (QLD, VIC, WA). Similarly, though digital literacy was a common feature of the way strategies conceived of STEM education only three of the strategies have a strong emphasis on building student digital literacy, supported through resourcing and
Table 3. Analyses of the way each jurisdiction’s strategy conceives of STEM education

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>STEM capabilities</th>
<th>STEM dispositions</th>
<th>STEM educational practices</th>
<th>Equity</th>
<th>Trajectories</th>
<th>Educator capacities</th>
</tr>
</thead>
<tbody>
<tr>
<td>National</td>
<td>Creative thinking</td>
<td>Interest</td>
<td>Individual STEM disciplines and cross-disciplinary</td>
<td></td>
<td>EC to Year 12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Critical analysis</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Problem solving</td>
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</tr>
<tr>
<td></td>
<td>Mathematical, scientific and technological literacy</td>
<td></td>
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<tr>
<td></td>
<td>STEM discipline skills</td>
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</tr>
<tr>
<td>NSVY</td>
<td>Creative thinking</td>
<td>Curiosity</td>
<td>Inquiry</td>
<td>‘STEM education is for all students’</td>
<td>EC to Year 12</td>
<td>Career pathways</td>
</tr>
<tr>
<td></td>
<td>Critical analysis</td>
<td>Aspirations</td>
<td>Project-based learning</td>
<td>Integrated</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>STEM discipline knowledge</td>
<td></td>
<td>Interdisciplinary</td>
<td>Authentic contexts</td>
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<td></td>
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</tr>
<tr>
<td>QLD</td>
<td>Creative thinking</td>
<td>Digital technologies</td>
<td>Coding</td>
<td>‘Lift participation of students including girls and Aboriginal and Torres Strait Islander students’</td>
<td>Career pathways</td>
<td>Innovate and engage with cutting edge science and teaching practice Access to specialist STEM teachers</td>
</tr>
<tr>
<td></td>
<td>Critical analysis</td>
<td></td>
<td>Robotics</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>SA</td>
<td>Collaboration</td>
<td>Inquiry</td>
<td>‘Give each child and student ... STEM knowledge and skills’</td>
<td></td>
<td>EC to Year 12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Problem solving</td>
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<td>Interdisciplinary thinking</td>
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<td>STEM discipline skills</td>
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<td></td>
<td>skills and knowledge</td>
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<tr>
<td>TAS</td>
<td>Collaboration</td>
<td>Resilience</td>
<td>Project-based learning</td>
<td>‘Access and challenge for all learners’</td>
<td>Career pathways</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Creative thinking</td>
<td>Growth mind-set</td>
<td>Interdisciplinary</td>
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<tr>
<td></td>
<td>Critical analysis</td>
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<td>Real world</td>
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<tr>
<td></td>
<td>Problem solving</td>
<td></td>
<td>Applied and contextualised</td>
<td></td>
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<tr>
<td></td>
<td>Project management</td>
<td></td>
<td>learning settings</td>
<td></td>
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<tr>
<td></td>
<td>Self-direction</td>
<td></td>
<td>Complements</td>
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</tr>
</tbody>
</table>
|              | STEM literacy                              |                   |                            |                                                 |                       |                                      | (continued)
<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>STEM capabilities</th>
<th>STEM educational practices</th>
<th>Equity</th>
<th>Trajectories</th>
<th>Educator capacities</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIC</td>
<td>Experimenting</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Hypothesising</td>
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<td></td>
<td>Investigating</td>
<td></td>
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<tr>
<td></td>
<td>Problem solving</td>
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<td></td>
<td>Creative thinking</td>
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<tr>
<td></td>
<td>Critical analysis</td>
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<td>Ethical thinking</td>
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<td></td>
<td>STEM discipline skills</td>
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<tr>
<td></td>
<td>and knowledge</td>
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</tr>
<tr>
<td>WA</td>
<td>Collaboration</td>
<td>Integrated STEM disciplines</td>
<td>Raising the capabilities of all students</td>
<td>Career pathways</td>
<td>Lifelong learning</td>
</tr>
<tr>
<td></td>
<td>Communication</td>
<td>Inquiry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Creative thinking</td>
<td>Technologies</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Critical analysis</td>
<td>Problem-based learning</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Independent thinking</td>
<td>Authentication learning tasks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integrated knowledge</td>
<td>Real contexts</td>
<td></td>
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<tr>
<td></td>
<td>Problem solving</td>
<td>Explicit teaching of discipline consent</td>
<td></td>
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<tr>
<td></td>
<td>ICT skills</td>
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<tr>
<td></td>
<td>Numeracy</td>
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</tbody>
</table>

STEM: Science, Technology, Engineering, Mathematics; ACT: Australian Capital Territory; NSW: New South Wales; NT: Northern Territory; QLD: Queensland; SA: South Australia; TAS: Tasmania; VIC: Victoria; WA: Western Australia.
enrichment opportunities (National, QLD, VIC). This lack of consistency reflects the STEM education literature, where there is still a need to clearly articulate for educators how these capabilities are to be exercised in STEM learning environments.

**Dispositions**

Each of the strategies acknowledge the role of affect in effective STEM education in their conceptualisation (Table 3) and/or rationale; though, generally this element has only minor emphasis. Strategies tend to express their intent with vague phrases like ‘lift student engagement’ (National, p. 3) or ‘encourage greater interest... in STEM’ (WA, p. 2). While it is encouraging that dispositions such as interest, curiosity, aspiration, and confidence are cited within the strategies as being important for initiating and sustaining students’ motivation to pursue STEM learning and career paths, there is little attempt to operationalise these terms. Only the Tasmanian strategy flagged motivational constructs such as student self-direction and growth mindset that have been found to improve learner engagement in STEM.

Further, only three of the strategies include actions explicitly aiming to impact on student disposition (National, VIC, WA). These actions focus on building aspirations, curiosity and confidence. The actions explicitly identified are limited to building industry partnerships, a mathematics challenge, a research-based Early Childhood numeracy programme, and delivering STEM education professional learning. Given the strong evidence showing the role of affect on student success in STEM and engagement in STEM pathways, the limited consideration of ways to enhance STEM dispositions is a significant shortcoming across the Australian STEM strategies.

**Educational practices**

As shown in Table 3, all but the Victorian strategy include STEM educational practices in the conceptualisation of STEM education. The practices identified have a strong real-world and inquiry orientation; however, there is no consensus among the strategies as to whether STEM education should be delivered through the discrete disciplines, or as a learning experience where the disciplines are integrated, with the strategies variously describing ‘STEM’ as being four individual disciplines, cross-disciplinary, and/or inter-disciplinary.

To support building these STEM capabilities and dispositions, the strategies outline actions to transform educational practices. Encouragingly, given the evidence supporting inquiry learning in STEM education, the majority of strategies (National, NSW, SA, TAS, WA), have actions targeted at encouraging the adoption of inquiry or PBL pedagogies. Three strategies include actions aimed at ensuring STEM education is presented in an integrated way (NSW, TAS, WA). It is clear in the literature that the impact of both integrated curriculum and inquiry learning varies according to approach, context, and cohort; however, the strategies provide minimal description of how they conceived of these practices. All the strategies advocate building partnerships with industry, other educational institutions and the wider community, to improve the quality of STEM education (e.g. National, WA). While this has intuitive appeal, there is not yet conclusive evidence to support such actions (Gamse et al., 2017).

Three of the strategies (National, QLD, VIC) also place significant emphasis on digital learning practices. Each of these strategies establish a baseline action of implementing the set digital literacy curriculum. Victoria and Queensland have actions are focused on
extra-curricular measures such as competitions. The remaining actions included the provision of software for secondary schools and the support of digital learning experiences for early childhood. These actions do not appear to be a strong match to those described in the literature expanding access to learning environments, or improving problem solving and motivation for all students.

**Equity**

As discussed in the literature review, the extant research identifies equity issues for key groups in STEM education in Australia. As Table 3 shows, five strategies (NSW, SA, TAS, QLD, WA) address equity in their conceptualisation of STEM education. Of these, all except Queensland used broad statements such as 'STEM education is for all students', implying the inclusion of groups that are known to be marginalised. Only Queensland explicitly identified girls and indigenous students as groups requiring particular support, consistent with the research literature.

Three of the STEM strategies (National, VIC, SA) made explicit reference to equity issues in their rationales. The National strategy nominated girls, indigenous students, students from low socio-economic backgrounds, and students from non-metropolitan areas, as groups that need to be considered. The South Australian rationale explicitly discussed the under-representations of women and Indigenous people in STEM, and the Victorian rationale had a strong focus on girls in STEM education, with some mention of the impact of student socio-economic background. Four strategies (QLD, SA, VIC, WA) included actions explicitly aiming to impact on equity in STEM education, and these were limited. However, the few actions articulated relied heavily on having impact through short term interventions such as camps for girls, mentoring programmes for Indigenous children, and online STEM enrichment programmes for non-metropolitan and disadvantaged communities.

**Trajectories**

As Table 3 shows, there is some acknowledgement of STEM education trajectories in the way STEM is conceived by each of the strategies, though Tasmania and Queensland limit this to facilitating career pathways. Similarly, all rationales, implicitly or explicitly, give some consideration to STEM education trajectories. Universally, the rationales consider the role of STEM education in preparing students for future careers. Three of the rationales argue for the importance of STEM education to ensure senior secondary students continue on STEM learning pathways (National, QLD, VIC). Two of the rationales also acknowledge that STEM education begins in early childhood (National, VIC). Only the Victorian rationale makes explicit reference to stages of learning between early childhood and senior secondary, with a discussion of disengagement in STEM between Year 6 and Year 9.

Encouragingly, all strategies have actions focused on trajectories, with actions aiming at STEM education at the beginning and end of the formal learning journey. Aspiration building measures dominate, with all strategies including actions focused upon enhancing awareness of, and access to, career pathways and post-secondary opportunities throughout the schooling years. The literature argues that STEM education should begin well before children commence school; however, only three strategies have actions explicitly directed at STEM education in the early childhood years (National, SA, VIC). The research literature also makes it clear that each step of the learning journey is key to the development of a
student's STEM capabilities and dispositions. However, only Victoria and South Australia have explicit actions addressing STEM education for other stages of learning, and both only focus on Years 7 and 8.

**Educator capacities**

The research literature identifies a need for educators with sound STEM content knowledge, confidence to deliver STEM education programmes, and engaging STEM pedagogical approaches. Only one jurisdiction (QLD) explicitly describes the role of educators in their conceptualisation of STEM education; however, five of the rationales (National, NSW, QLD, SA, VIC) describe the importance of educator capacity for improving STEM education. These rationales highlight the importance of building teacher confidence and competence, both in terms of STEM expertise and engaging STEM pedagogy.

All jurisdiction strategies, with the exception of Tasmania, direct actions at raising the skills of educators. Each of these adopt actions to identifying and/or training of excellent STEM practitioners, and schools, to act as support and role models to others. There are several actions to improve the capacity and confidence of early childhood and primary teachers (National, SA, VIC), and other actions to provide mentoring to inspire secondary school STEM teachers (SA, VIC). Only two of the strategies (WA, SA) have actions directed at improving school leaders' capacity to drive the implementation of STEM education.

**Conclusion**

As a group, Australia's STEM education strategies align to the STEM education literature to some degree; however, no single strategy can be said to comprehensively address all the important themes arising in the STEM education literature. Several of the themes are addressed by the majority of the strategies. There is an emphasis in the strategies on developing STEM capabilities in students, and achieving this through research-supported educational practices such as inquiry and. Building educator capacity is seen as a key action for improving STEM education. The strategies strongly favour actions aimed at improving educator knowledge and confidence, and supporting the adoption of STEM education practices.

Other themes from the literature are less well addressed. While collectively the strategies acknowledge STEM education as a key part of a child’s entire learning journey, the strongest emphasis is on facilitating career pathways when exiting school. Less than half the strategies explicitly focus on STEM education in early childhood and even fewer consider maintaining student learning trajectories in between. Though most strategies allude to the importance of STEM dispositions and acknowledge various equity issues, these matters receive less explicit treatment in the articulated actions.

The recently released Australian STEM education strategies are designed to guide the actions of educational leaders and practitioners for up to a decade. While it is encouraging to see some of the themes from the literature into effective STEM education reflected in the strategies, it is concerning that issues regarding STEM dispositions, equity, and transitions within and between educational sectors, are not given significant attention. The implication of these deficits is that educators and leaders responding to the various strategies may miss addressing aspects crucial for improving STEM education for all children at all stages of learning.
Acknowledgement

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Note

1. Australia has six state and two territory governments. The states and territories have responsibility for the delivery of school education; however, the federal government plays a role in education through policy and funding (Australian Government Department of Education and Training, 2017).

References


Steve Murphy is a PhD Candidate and sessional academic at Charles Sturt University, Albury-Wodonga, Australia. Steve’s doctoral research is examining successful STEM education practices in rural secondary schools. Steve is an experienced STEM Educator, Instructional Leader and Principal. He has worked in government and independent schools, and in primary, secondary and tertiary education sectors.

Amy MacDonald is a Senior Lecturer in the School of Education at Charles Sturt University, Albury-Wodonga, Australia. Amy specialises in early childhood mathematics education. Her research interests also include STEM education, educational transitions, and early childhood educators’ professional learning. She is experienced in mixed-methods research, and has particular expertise in researching with young children. Amy has received
several awards for her work, including the Mathematics Education Research Group of Australasia Early Career Award, and an Australian Government Office for Learning and Teaching Citation for Outstanding Contribution to Student Learning for her approaches to mathematics education. Amy has previously worked as an early years teacher in regional Australia.

Lena Danaia is an Associate Professor in the School of Teacher Education at Charles Sturt University, Bathurst, Australia. Lena specialises in science and technology curriculum and is experienced in mixed methods research with a strong focus on surveys. Lena’s research interests include student engagement in school science, STEM education and astronomy education. She is experienced in working on large-scale research projects that involve cross-institution collaborations. Lena has also been recognised nationally for her outstanding contributions to learning and teaching where she was awarded an Australian Learning and Teaching Council (ALTC) Teaching Excellence Award. Lena previously worked as a teacher in both Australia and the UK.

Cen Wang is a Research Fellow in the School of Teacher Education at Charles Sturt University, Bathurst, Australia. Her research focuses on understanding the diverse ways that children develop, learn and achieve academic success. She also explores personal and contextual factors that influence children’s learning, motivation and social emotional well-being. Cen is also experienced in managing large longitudinal datasets and applying advanced statistical analyses.

Appendix C. Information sheets

C.1 STEM Leader / Teacher Information sheet – interview

PARTICIPANT INFORMATION SHEET (STEM leader)
Practices contributing to high STEM performance in rural Victorian
government secondary schools

Researchers:
Chief Investigator:  
Mr. Steven Murphy (M Ed. B.Sc.) – Ph.D. Candidate, School of Education

Project Supervisors:
Dr. Lena Dangaia  
Associate Professor – School of Teacher Education

Dr. Amy MacDonald  
Senior Lecturer – School of Education

Invitation
Your school has been identified as high performing in STEM (science, technology, engineering and mathematics) education. You are invited to participate in a research study of the practices of high STEM performing schools in rural Victoria.
The study is being conducted by Mr. Steven Murphy, an experienced STEM teacher and school leader, from the School of Education at Charles Sturt University.

Before you decide whether or not you wish to participate in this study, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully and discuss it with others if you wish.

1. What is the purpose of this study?
STEM skills and knowledge are seen as essential to thrive in our rapidly changing world. However, Australian students’ participation and achievement in STEM subjects have been decreasing over many years. Non-metropolitan or rural Australian students are six months or even further behind in STEM achievement compared to students in major cities. This study will identify rural schools performing much better than average in STEM. It will then study the practices of these high STEM performing rural schools to find ways to improve STEM education for rural students.

2. Why have I been invited to participate in this study?
We are inviting all STEM leaders at your school to participate in one-on-one interviews about the implementation and impact of practices that have contributed to your school’s STEM performance.

3. What does this study involve?
If you agree to participate, you will be asked to participate in a 30 minute one-on-one interview during Term 2 or 3, 2018 at a time and place convenient to you. The interview will be conducted by the Chief Investigator who will make an audio recording of the interview. You will be asked about your perception of the implementation and impact of practices that have contributed to your school’s STEM performance.

4. Are there risks and benefits to me in taking part in this study?
The interview will focus on your perception of STEM education at your school so there will be an extremely low risk that any sensitive issues will be raised. If questions are asked that cause you discomfort or distress you may withdraw from the interview at any time and without explanation. The researcher will work with the welfare supports in the Department of Education and Training if you require any support. We cannot promise you any benefit from participating in this research.

5. How is this study being paid for?
This research is paid for by the Chief Investigator's Research Training Program scholarship.

6. Will taking part in this study (or travelling to) cost me anything, and will I be paid?
Participation in this study will not cost you anything. You will receive no payment for participating in this study.

7. What if I don't want to take part in this study?
Participation in this research is entirely your choice. Only those people who give their informed consent will be included in the project. Whether or not you decide to participate is your decision and will not disadvantage you.
If you do decide to participate, you may withdraw from the project at any time without giving a reason and have the option of withdrawing any data which identifies you.

8. What if I participate and want to withdraw later?
You have the option to withdraw your data if you decide to withdraw after the interview.

10. How will my confidentiality be protected?
Your name will not be recorded as part of this study. Instead, your responses will be attributed to a pseudonym (false name). Any information collected by the researchers which might identify you will be stored securely and only accessed by the researchers and will not be disclosed unless you consent otherwise, except as required by law. There are limits on assurances of confidentiality as law may subpoena research data/records. Data will be retained for at least 5 years at Charles Sturt University.

11. What will happen to the information that I give you?
The audio recording of the group interview will be transcribed and you will be able to review the recording and/or transcripts. These interviews will be one source of data analysed as part of a case study of high STEM performing rural schools. This study will form part of a thesis to be submitted for Mr. Steven Murphy's degree, and will also be published in papers in academic journals and presented at conferences. Individuals will not be identified in any reports or publications arising from this project. A summary report will be made available to all participants in this study.

12. What should I do if I want to discuss this study further before I decide?
If you would like further information please contact Mr. Steven Murphy on 0478 450 342 or at smurphy@cssu.edu.au, from whom potential participants can obtain further information about the project.

13. Who should I contact if I have concerns about the conduct of this study?
Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any complaints or reservations about the ethical conduct of this project, you may contact the Committee on (02) 6336 4520 or ethics@cssu.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Thank you for considering this invitation. This information sheet is for you to keep.
PARTICIPANT INFORMATION SHEET (teacher)

Practices contributing to high STEM performance in rural Victorian government secondary schools

Researchers:

Chief Investigator:
Mr. Steven Murphy (M.Ed. B.Sc.) – Ph.D. Candidate, School of Education

Project Supervisors:
Dr. Lena Danaia – Associate Professor – School of Teacher Education
Dr. Amy MacDonald – Senior Lecturer – School of Education

Invitation

Your school has been identified as high performing in STEM (science, technology, engineering and mathematics) education. You are invited to participate in a research study on the practices of high STEM performing schools in rural Victoria.

The study is being conducted by Mr. Steven Murphy, an experienced STEM teacher and school leader, from the School of Education at Charles Sturt University.

Before you decide whether or not you wish to participate in this study, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully and discuss it with others if you wish.

1. What is the purpose of this study?

STEM skills and knowledge are seen as essential to thrive in our rapidly changing world. However, Australian students’ participation and achievement in STEM subjects have been decreasing over many years. Non-metropolitan or rural Australian students are six months or more even further behind in STEM achievement compared to students in major cities. This study will identify rural schools performing much better than average in STEM. It will then study the practices of these high STEM performing rural schools to find ways to improve STEM education for rural students.

2. Why have I been invited to participate in this study?

We are inviting all teachers at your school to participate in a brief online anonymous questionnaire about their perception of the practices contributing to your school’s STEM performance.

3. What does this study involve?

If you agree to participate, you will be asked to complete an online anonymous questionnaire available at [https://www.surveymonkey.com/r/SSTSVY2G]. This questionnaire should take no more than 20 minutes. The questionnaire will ask for basic information about your qualification, teaching load and teaching experience. It will then ask you multiple choice, ratings and open-ended questions about the practices at your school that may have contributed to its STEM performance.

4. Are there risks and benefits to me in taking part in this study?

The questionnaire will focus on your experience of STEM education at your school and there will be an extremely low risk that any sensitive issues will be raised. If questions are asked that cause you discomfort or distress you may withdraw from the interview at any time and without explanation. The researcher will work with the interviewee at your school if you require any support. We cannot promise you any benefit from participating in this research.
5. How is this study being paid for?
This research is paid for by the Chief Investigator's Research Training Program scholarship.

6. Will taking part in this study (or travelling to) cost me anything, and will I be paid?
Participation in this study will not cost you anything. You will receive no payment for participating in this study.

7. What if I don’t want to take part in this study?
Participation in this research is entirely your choice. Only those people who give their informed consent will be included in the project. Whether or not you decide to participate is your decision and will not disadvantage you.
If you do decide to participate, you may withdraw from the project at any time without giving a reason and have the option of withdrawing any data which identifies you.

8. What if I participate and want to withdraw later?
As the questionnaire is anonymous it is not possible to withdraw your data after you have submitted your responses.

10. How will my confidentiality be protected?
The questionnaire is completed anonymously. Any information collected by the researchers will be stored securely and only accessed by the researchers. Data will be retained for at least 5 years at Charles Sturt University.

11. What will happen to the information that I give you?
The questionnaire will be one source of data analysed as part of a case study of high STEM performing rural schools. This study will form part of a thesis to be submitted for Mr Steven Murphy’s degree, and will also be published in papers in academic journals and presented at conferences. Individuals will not be identified in any reports or publications arising from this project. A summary report will be made available to all participants in this study.

12. What should I do if I want to discuss this study further before I decide?
If you would like further information please contact Mr Steven Murphy on 0478 450 842 or at smurphy@csu.edu.au, from whom potential participants can obtain further information about the project.

13. Who should I contact if I have concerns about the conduct of this study?
Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any complaints or reservations about the ethical conduct of this project, you may contact the Committee on (02) 6338 4820 or ethics@csu.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Thank you for considering this invitation. This information sheet is for you to keep.
PARTICIPANT INFORMATION SHEET (Student)

Practices contributing to high STEM performance in rural Victorian government secondary schools

Researchers:
Chief Investigator: Mr. Steven Murphy (M.Ed. B.Sc.) – Ph.D. Candidate, School of Education
Project Supervisors:
Dr. Lana Danaia – Associate Professor – School of Teacher Education
Dr. Amy MacDonald – Senior Lecturer – School of Education

Invitation
Your school has been identified as high performing in STEM (science, technology, engineering and mathematics) education. You are invited to participate in a research study on the practices of high STEM performing schools in rural Victoria. The study is being conducted by Mr. Steven Murphy from the School of Education at Charles Sturt University.

Before you decide whether or not you wish to participate in this study, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully and discuss it with others if you wish.

1. What is the purpose of this study?
STEM skills and knowledge are seen as essential to thrive in our rapidly changing world. However, Australian students’ participation and achievement in STEM subjects have been decreasing over many years. Non-metropolitan or rural Australian students are six months or more even further behind in STEM achievement compared to students in major cities. This study will identify rural schools performing much better than average in STEM. It will then study the practices of these high STEM performing rural schools to find ways to improve STEM education for rural students.

2. Why have I been invited to participate in this study?
We are seeking five Year 12 students studying Biology, Chemistry, Physics, Mathematical Methods and/or Specialist Mathematics, and five Year 12 students not studying any of these subjects, to participate in group interviews about STEM education at your school.

3. What does this study involve?
If you agree to participate, you will be asked to participate in a 30-minute group interview at your school. The group interview will involve yourself and up to 4 other students and will ask about your experiences with STEM education at your school. The interview will be conducted by the Chief Investigator who will make an audio recording of the interview.

4. Are there risks and benefits to me in taking part in this study?
The interview will focus on your experience of STEM education at your school so there will be an extremely low risk that any sensitive issues will be raised. If questions are asked that cause you discomfort or distress you may withdraw from the interview at any time and without explanation. The researcher will work with the welfare supports at your school if you require any support. We cannot promise you any benefit from participating in this research.

5. How is this study being paid for?
This research is paid for by the Chief Investigator’s Research Training Program scholarship.
6. Will taking part in this study (or travelling to) cost me anything, and will I be paid? Participation in this study will not cost you anything. You will receive no payment for participating in this study.

7. What if I don’t want to take part in this study? Participation in this research is entirely your choice. Only those people who give their informed consent will be included in the project. Whether or not you decide to participate is your decision and will not disadvantage you. If you do decide to participate, you may withdraw from the project at any time without giving a reason.

8. What if I participate and want to withdraw later? Your responses in the group interview will be de-identified. As this is a group interview you will not have the option to withdraw your data after you participate in the interview.

10. How will my confidentiality be protected? Your name will not be recorded as part of this study. Instead, your responses will be attributed to a pseudonym (true name). Any information collected by the researchers which might identify you will be stored securely and only accessed by the researchers and will not be disclosed unless you consent otherwise, except as required by law. There are limits on assurances of confidentiality as law may subpoena research data/records. Data will be retained for at least 5 years at Charles Sturt University.

As you are participating in a group interview you are requested to maintain the confidentiality of the group discussion and not divulge the specific content to outside parties.

11. What will happen to the information that I give you? The audio recording of the group interview will be transcribed and you will be able to review the recording and/or transcripts. These interviews will be one source of data analysed as part of a case study of high STEM performing rural schools. This study will form part of a thesis to be submitted for Mr Steven Murphy’s degree, and will also be published in papers in academic journals and presented at conferences. Individuals will not be identified in any reports or publications arising from this project. A summary report will be made available to all participants in this study.

12. What should I do if I want to discuss this study further before I decide? If you would like further information please contact Mr Steven Murphy on 0473 450 342 or at smurphy@csu.edu.au, from whom potential participants can obtain further information about the project.

13. Who should I contact if I have concerns about the conduct of this study? Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any complaints or reservations about the ethical conduct of this project, you may contact the Committee on (02) 6338 4528 or ethics@csu.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Thank you for considering this invitation. This information sheet is for you to keep.
PARTICIPANT INFORMATION SHEET (Parent)
Practices contributing to high STEM performance in rural Victorian government secondary schools

Researchers:
Chief Investigator:
Mr. Steven Murphy (M.Ed. B.Sc.) – Ph.D. Candidate, School of Education

Project Supervisors:
Dr. Lena Danaia
Associate Professor – School of Teacher Education

Dr. Amy MacDonald
Senior Lecturer – School of Education

Invitation
Your child’s school has been identified as high performing in STEM (science, technology, engineering and mathematics) education. Your child is invited to participate in a research study on the practices of high STEM performing schools in rural Victoria.

The study is being conducted by Mr. Steven Murphy from the School of Education at Charles Sturt University.

Before you decide whether or not you wish for your child to participate in this study, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully and discuss it with others if you wish.

1. What is the purpose of this study?
STEM skills and knowledge are seen as essential to thrive in our rapidly changing world. However, Australian students’ participation and achievement in STEM subjects have been decreasing over many years. Non-metropolitan or rural Australian students are six months or more even further behind in STEM achievement compared to students in major cities. This study will identify rural schools performing much better than average in STEM. It will then study the practices of these high STEM performing rural schools to find ways to improve STEM education for rural students.

2. Why have I been invited to participate in this study?
We are seeking five Year 12 students studying Biology, Chemistry, Physics, Mathematical Methods and/or Specialist Mathematics, and five Year 12 students not studying any of these subjects, to participate in group interviews about STEM education at your child’s school.

3. What does this study involve?
If you agree for your child to participate, your child will participate in a 30 minute group interview at ______ am/pm on ______ 2018 at the school. The group interview will involve your child and up to 4 other students and will ask about your child’s experiences with STEM education at the school. The interview will be conducted by the Chief Investigator who will make an audio recording of the interview.

4. Are there risks and benefits to me in taking part in this study?
The interview will focus on your child’s experience of STEM education at the school so there will be an extremely low risk that any sensitive issues will be raised. If questions are asked that cause discomfort or distress your child may withdraw from the interview at any time and without explanation. The researcher will work with the welfare supports at your school if your child requires any support. We cannot promise you or your child any benefit from participating in this research.

5. How is this study being paid for?
This research is paid for by the Chief Investigator’s Research Training Program scholarship.
6. Will taking part in this study (or travelling to) cost me anything, and will I be paid?
Participation in this study will not cost you anything. Your child will receive no payment for participating in this study.

7. What if I don’t want to take part in this study?
Participation in this research is entirely your choice. Only those people who give their informed consent will be included in the project. Whether or not you decide to consent for your child to participate is your decision and will not disadvantage you or your child. If you do decide to consent for your child to participate, your child may withdraw from the project at any time without giving a reason.

8. What if I participate and want to withdraw later?
Your child’s responses in the group interview will be de-identified. As this is a group interview you will not have the option to withdraw your child’s data after your child has participated in the interview.

9. How will my confidentiality be protected?
Your child’s name will not be recorded as part of this study. Instead, your child’s responses will be attributed to a pseudonym (false name). Any information collected by the researchers which might identify your child will be stored securely and only accessed by the researchers and will not be disclosed unless you consent otherwise, except as required by law. There are limits on assurances of confidentiality as lay may subpoena research data records. Data will be retained for at least 5 years at Charles Sturt University.

As your child is participating in a group interview your child is requested to maintain the confidentiality of the group discussion and not divulge the specific content to outside parties.

10. What will happen to the information that I give you?
The audio recording of the group interview will be transcribed and you will be able to review the recording and/or transcripts. These interviews will be one source of data analysed as part of a case study of high STEM performing rural schools. This study will form part of a thesis to be submitted for Mr Steven Murphy’s degree, and will also be published in papers in academic journals and presented at conferences. Individuals will not be identified in any reports or publications arising from this project. A summary report will be made available to all participants in this study.

11. What should I do if I want to discuss this study further before I decide?
If you would like further information please contact Mr. Steven Murphy on 0478 450 312 or at smurphy@csu.edu.au, from whom potential participants can obtain further information about the project.

12. Who should I contact if I have concerns about the conduct of this study?
Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any complaints or reservations about the ethical conduct of this project, you may contact the Committee on (02) 6036 4528 or ethics@csu.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Any issues you raise will be treated in confidence and investigated fully and you will be informed of the outcome.

Thank you for considering this invitation.
This information sheet is for you to keep.
Appendix D. Consent forms

D.1 STEM leader / teacher consent form

CONSENT FORM (STEM leader)
Practices contributing to high STEM performance in rural Victorian government secondary schools

Researchers:
Chief Investigator:
Mr. Steven Murphy (M.Ed. B.Sc.) – Ph.D. Candidate, School of Education
Project Supervisors:
Dr. Lelia Deniada
Dr. Amy MacDonald
Associate Professor – School of Teacher Education
Senior Lecturer – School of Education

I agree to participate in the above research project and give my consent freely.
I understand that the project will be conducted as described in the Information Statement, a copy of which I have retained.
I understand I can withdraw from the project at any time and do not have to give any reason for withdrawing.

I consent to:
- Participating in a 30 minute interview with the Chief Investigator about STEM education at my school.

I understand that my personal information will remain confidential to the researchers. I have had the opportunity to have my questions about the project answered to my satisfaction.

Print Name: __________________________

Signature: ____________________________ Date: ____________________

NOTE: Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any complaints or reservations about the ethical conduct of this project, you may contact the Committee on (02) 6330 4620 or ethics@csu.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
CONSENT FORM (student)
Practices contributing to high STEM performance in rural Victorian government secondary schools

Researchers:
Chief Investigator:
Mr. Steven Murphy (M.Ed. B.Sc.) – Ph.D. Candidate, School of Education

Project Supervisors:
Dr. Lena Danaia
Associate Professor – School of Teacher Education
Dr. Amy MacDonald
Senior Lecturer – School of Education

I agree to participate in the above research project and give my consent freely.
I understand that the project will be conducted as described in the Information Statement, a copy of which I have retained.
I understand I can withdraw from the project at any time and do not have to give any reason for withdrawing. I understand that as this is a group interview, I will not be able to withdraw my data if I choose to no longer participate.

I consent to:
- Participating in a 30 minute group interview with the Chief Investigator and a small group of other Year 12 students about STEM education

I understand that my personal information will remain confidential to the researchers. I have had the opportunity to have my questions about the project answered to my satisfaction. (Please note that if you are under 16 years old your parent or guardian will need to sign a separate consent form.)

Print Name: ____________________________
Signature: ____________________________ Date: ____________________________

NOTE: Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any complaints or reservations about the ethical conduct of this project, you may contact the Committee on (02) 6338 4629 or ethics@csu.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
CONSENT FORM (parent)

Practices contributing to high STEM performance in rural Victorian government secondary schools

Researchers:
Chief Investigator:
Mr. Steven Murphy (M.Ed. B.Sc.) – Ph.D. Candidate, School of Education
Project Supervisors:
Dr. Lena Danaia
Dr. Amy MacDonald
Associate Professor – School of Teacher Education
Senior Lecturer – School of Education

I agree for my child to participate in the above research project and give my consent freely. I understand that the project will be conducted as described in the Information Statement, a copy of which I have retained.
I understand my child can withdraw from the project at any time and does not have to give any reason for withdrawing. I understand that, as this is a group interview, I will not be able to withdraw my child’s data if he/she chooses to no longer participate.

I consent for my child to:
- Participating in a 30 minute group interview with the Chief Investigator and up to 4 other Year 12 students about STEM education.

I understand that my child’s personal information will remain confidential to the researchers. I have had the opportunity to have my questions about the project answered to my satisfaction.

Child’s Name: ____________________________________________

Parent/Caregiver’s Name: ___________________________________

Signature: ___________________________ Date: ___________________________

NOTE: Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any complaints or reservations about the ethical conduct of this project, you may contact the Committee on (02) 6338 4878 or ethics@csu.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Appendix E. Interview questions

E.1 STEM leader / teacher interview questions

Interview Questions (STEM leader)
Practices contributing to high STEM performance in rural Victorian government secondary schools

Introduction
Your school has been identified as high performing in STEM (science, technology, engineering and mathematics) education. The principal of the school has given permission for this research study to be conducted at the school. The study is being conducted by me, Steven Murphy, from the School of Education at Charles Sturt University. The study is being carried out as part of my PhD research, not in my role as a Teacher or Principal with the Department of Education and Training.

Australian students’ participation and achievement in STEM subjects have been decreasing over many years. Non-metropolitan or rural Australian students are six months or more even further behind in STEM achievement compared to students in major cities. My research has identified rural schools, including your school, performing much better than average in STEM. This interview is part of a study to investigate why your school is high STEM performing to find ways to improve STEM education for other rural students.

This interview is going to be recorded.

The interview will focus on your experience as a leader of STEM education at your school.

Are you still happy to participate? Do you have any questions?

Interview Questions

1. What do you feel are the largest contributors to student engagement in STEM at your school?
   What about the contributors to student achievement?
2. How do you think the elements contributing to your school’s success in STEM were developed? How are these elements maintained?
3. What challenges does your school face in STEM education? How are these overcome?
4. What (if any) impact have the following had on your school’s success in STEM education?
   a. Integration of the STEM disciplines
   b. A focus on problem solving, creativity and/or critical thinking in STEM
   c. A focus on ensuring all students feel confident, motivated and engaged in STEM learning
   d. A focus on encouraging students to consider STEM pathways and STEM careers
   e. Connecting STEM learning to the student’s world or real world applications
   f. Professional learning and support for STEM teachers
   g. Using connections to community, industry and/or tertiary institutions as part of the STEM program.

Conclusion
Thank you for your time. The audio recording of this interview will be transcribed and will be one source of data analysed as part of a case study of high STEM performing rural schools. This study will form part of my thesis, and will also be published in papers in academic journals and presented at conferences. You will not be identified in any reports or publications arising from this project. A summary report will be made available to you through your school.

If any of the conversations we have had have caused you discomfort or distress please refer to the information statement to seek advice or support as needed.
E.2 Year 12 group interview questions

Interview Questions (Year 12 Group Interview)
Practices contributing to high STEM performance in rural Victorian government secondary schools

Introduction
Your school has been identified as high performing in STEM (science, technology, engineering and mathematics) education. The principal of the school has given permission for this research study to be conducted at the school. The study is being conducted by me, Steven Murphy, from the School of Education at Charles Sturt University. The study is being carried out as part of my PhD research, not in my role as a Teacher or Principal with the Department of Education and Training.

Australian students’ participation and achievement in STEM subjects have been decreasing over many years. Non-metropolitan or rural Australian students are six months or more even further behind in STEM achievement compared to students in major cities. My research has identified rural schools, including your school, performing much better than average in STEM. This interview is part of a study to investigate why your school is high STEM performing to find ways to improve STEM education for other rural students.

This interview is going to be recorded. I will ask a question and then each of you will be given an opportunity to respond in turn. You do not have to give an answer for each question. Once everyone has had an opportunity to answer, you will also be asked if you have any further comments. Please remember that what is discussed today is to remain confidential.

The interview will focus on your experience of STEM education throughout your education at your school so there will be an extremely low risk that any sensitive issues will be raised. If questions are asked that cause you discomfort or distress you may withdraw from the interview at any time and without explanation.

Is there anyone who does not wish to participate? Are there any other questions?

Interview Questions

1. What are some of the best learning experiences you had studying Science, Maths or Technology before you began VCE? Why were these some of the best learning experiences in those subjects?
2. Describe how the teachers of Science, Maths and Technology teach at your school.
3. Describe how students at your school learn Science, Maths and Technology.
4. How does your school encourage student interest in STEM?
5. Why do you think your school is doing better in STEM education than other similar schools?

Conclusion
Thank you for your time. The audio recording of this interview will be transcribed and will be one source of data analysed as part of a case study of high STEM performing rural schools. This study will form part of my thesis, and will also be published in papers in academic journals and presented at conferences. You will not be identified in any reports or publications arising from this project. A summary report will be made available to you through your school.

Please remember that what is discussed today is to remain confidential. If any of the conversations we have had have caused you discomfort or distress please refer to the information statement to seek advice or support as needed.
Appendix F. Online STEM educator survey content

Survey of educator perspectives of the own and their school’s STEM education practices

Introduction
Your school has been identified as high performing in STEM (Science, Technology, Engineering and Mathematics) education. Your school was classified as a high STEM performing school by comparing it to other government schools in similar locations and serving communities of similar background using VCE enrolment and assessment data from Science, Technology and Mathematics.

Steve Murphy, an experienced rural STEM educator and educational leader, and is currently a PhD candidate with Charles Sturt University. He is seeking to understand the practices leading to STEM success in non-metropolitan schools such as yours. The hope is that your school’s experience and STEM education practices can be used to help similar schools to improve STEM education for their students.

This brief anonymous questionnaire seeks information about your expertise and experience as a STEM educator (either as a teacher of Science, Mathematics, Technology, or any combination of these subjects), your teaching practice, and your perspectives on what has contributed to your school’s success in STEM education. Some questions ask about teaching and learning strategies thought to improve STEM education. Others are open ended, seeking your insights on STEM education at your school.

The survey is expected to take 15-20 minutes.

Questions about you as a STEM educator
This section of the survey aims to build a profile of the teaching team that have contributed to your school’s STEM education success.

2. What other, if any, qualifications do you hold?
3. How many years have you taught at your current school?
4. How many years have you been teaching?
5. What other, if any, relevant work experience do you have?
6. What subjects are you qualified to teach? (List all, including non-STEM subjects)
7. What subjects and year levels do you teach this year? (List all, including non-STEM subjects)
8. What subjects and year levels have you taught in the past? (List all, including non-STEM subjects)
9. Over the past twelve months have you taught any Year 7-10 STEM subjects? YES/NO (Survey logic to direct participants to relevant questions from here)
10. Over the past twelve months have you taught any VCE STEM subjects? YES/NO (Survey logic to direct participants to relevant questions from here)

Questions about STEM education planning (Years 7-10)
Think any STEM education units you have planned and/or delivered to Years 7-10 over the past twelve months. How often do your units include the following elements?

1

330
<table>
<thead>
<tr>
<th>My STEM education units over the past 12 months ...</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Include pre-assessment of my students' knowledge in the subject</td>
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<tr>
<td>2. Include pre-assessment of my students' skills in the subject</td>
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<tr>
<td>3. Include pre-assessment of my students' attitudes and feelings about the subject</td>
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<tr>
<td>4. Aim to develop knowledge and skills from more than one STEM discipline</td>
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<tr>
<td>5. Aim to develop knowledge and skills from a STEM discipline and any other discipline (e.g., Art, Humanities)</td>
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<tr>
<td>6. Provide significant opportunities for student choice/input</td>
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<tr>
<td>7. Are connected to real world contexts</td>
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<td>8. Are connected to student's current lives</td>
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<tr>
<td>9. Connect explicitly to STEM related careers</td>
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<tr>
<td>10. Involve working with the community groups</td>
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<tr>
<td>11. Involve working with businesses or industry</td>
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<tr>
<td>12. Involve working with universities or TAPES</td>
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<tr>
<td>13. Require students to model real world situations</td>
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<tr>
<td>14. Allow students to work on real-world projects</td>
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<td>15. Require students to design useful products</td>
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<tr>
<td>16. Require students present to their work to audiences other than the teacher</td>
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</tbody>
</table>

Comment (Please expand on any of your responses that you feel require further elaboration or clarification)

Questions about STEM education practice (Years 7-10)
Think about the teaching and learning activities that you have used in your Years 7-10 STEM classes over the past twelve months. How frequently do you use the following types of activities...

<table>
<thead>
<tr>
<th>Activities I've used in Years 7-10 STEM classes over the past 12 months ...</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
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</thead>
<tbody>
<tr>
<td>1. Involve collaborative learning</td>
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<tr>
<td>2. Involve students working individually</td>
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<tr>
<td>3. Require creative thinking</td>
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<tr>
<td>4. Require critical thinking</td>
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<tr>
<td>5. Require working on complex problems that have multiple possible solutions</td>
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</tbody>
</table>
6. are 'hands-on' working with materials and equipment
7. Incorporate competition
8. Are located outside of the standard classroom
9. require student use of digital technologies
10. Involve working with other staff, volunteers or experts

Comment (Please expand on any of your responses that you feel require further elaboration or clarification)

Questions about VCE STEM subjects teaching (VCE)
Think any VCE STEM subjects you have taught over the past 12 months. How often did your teaching include the following elements?

<table>
<thead>
<tr>
<th>Over the past 12 months in my VCE STEM teaching</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. used pre-assessment of my students' knowledge in the area of study</td>
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<tr>
<td>2. used pre-assessment of my students' skills in the area of study</td>
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<tr>
<td>3. used pre-assessment of my students' attitudes and feelings towards the area of study</td>
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<tr>
<td>4. Connected learning to real world contexts</td>
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<tr>
<td>5. Connected learning to student's current lives</td>
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<tr>
<td>6. Connected learning explicitly to STEM related careers</td>
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<tr>
<td>7. Presented activities that required creative thinking</td>
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<td>8. Presented activities that required critical thinking</td>
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<td>9. Presented activities that required solving complex problems with multiple possible solutions</td>
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<tr>
<td>10. Used collaborative learning activities</td>
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<tr>
<td>11. Used 'hands-on' activities (working with materials and equipment)</td>
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<tr>
<td>12. Incorporated student use of digital technologies</td>
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<tr>
<td>13. Included learning activities outside the standard classroom</td>
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Comment (Please expand on any of your responses that you feel require further elaboration or clarification)
Questions about your professional learning and STEM education

Reflect upon your STEM associated professional learning activities at your current school. To what extent do you agree with the following statements?

<table>
<thead>
<tr>
<th>At my school STEM professional learning ...</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Unsure</th>
<th>Agree</th>
<th>Strongly agree</th>
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</thead>
<tbody>
<tr>
<td>1. is strongly supported by leadership</td>
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<td>2. involves staff from several disciplines</td>
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<td>3. supports improvement in multiple disciplines</td>
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<td>4. is held on-site</td>
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<td>5. is led by our own teachers</td>
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<td>6. is led by an expert</td>
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<td>7. centres on school identified needs</td>
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<td>8. involves cycles of reflection, action and evaluation to improve practice</td>
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<td>9. is informed by educational research</td>
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<td>10. involves mentoring between teachers</td>
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</table>

Questions about the success of your school’s STEM education programs

Please answer the following questions as fully as you are able to.

Your school has been identified as having high participation and achievement in STEM education relative to similar schools.

1. How have your school’s STEM teachers contributed to your school’s success in STEM education?

2. How have your school’s resources and learning environment contributed to your school’s success in STEM education?

3. How have your school’s leaders contributed to your school’s success in STEM education?

4. How have your school’s students contributed to your school’s success in STEM education?

5. How has your school’s wider community contributed to your school’s success in STEM education?
6. What are the greatest hurdles your school faces in achieving success in STEM education?

7. What factor(s) are the most important in overcoming these hurdles?
Appendix G. Research in Victorian Government Schools and/or Early Childhood Settings (RISEC) approval notice

2017_003441

Mr Steven Murphy
School of Education
Charles Sturt University
PO Box 789
ALBURY NSW 2640

Dear Mr Murphy

Thank you for your application of 30 June 2017 in which you request permission to conduct research in Victorian government schools titled *Practices contributing to high STEM performance in rural Victorian government secondary schools: Study 1 – Identifying high STEM performing rural Victorian government secondary schools, Study 2 – Multi-case study of high STEM performing rural Victorian government secondary schools*.

I am pleased to advise that on the basis of the information you have provided your research proposal is approved in principle subject to the conditions detailed below.

1. Department approved research projects currently undergoing a Human Research Ethics Committee (HREC) review are required to provide the Department with evidence of the HREC approval once complete.

2. The research is conducted in accordance with the final documentation you provided to the Department of Education and Training.

3. Separate approval for the research needs to be sought from school principals. This is to be supported by the Department of Education and Training approved documentation and, if applicable, the letter of approval from a relevant and formally constituted Human Research Ethics Committee.

4. The project is commenced within 12 months of this approval letter and any extensions or variations to your study, including those requested by an ethics committee must be submitted to the Department of Education and Training for its consideration before you proceed.

5. As a matter of courtesy, you advise the relevant Regional Director of the schools or governing body of the early childhood settings that you intend to approach. An outline of your research and a copy of this letter should be provided to the Regional Director or governing body.
6. You acknowledge the support of the Department of Education Training in any publications arising from the research.

7. The Research Agreement conditions, which include the reporting requirements at the conclusion of your study, are upheld. A reminder will be sent for reports not submitted by the study's indicative completion date.

I wish you well with your research. Should you have further questions on this matter, please contact Youla Michaels, Project Support Officer, Insights and Evidence Branch, by telephone on (03) 9637 2707 or by email at michaels.youla.vic@jobmail.vic.gov.au.

Yours sincerely,

[Signature]

John Tomaino
Director
Insights and Evidence

8/8/2017
Appendix H. Human Research Ethics Approval (protocol number 100/2017/23)

4 September 2017
Mr Steve Murphy
School of Education

Dear Steve,
Thank you for providing revisions to your ethics application to the Arts and Education Faculty Human Ethics Committee for the proposal Practices contributing to high STEM performance in rural Victorian government secondary schools.

The Faculty of Arts and Education Human Ethics Committee has approved your proposal for 12 months from 4 September 2017.

The protocol number issued with respect to this project is 100/2017/23. Please be sure to quote this number when responding to any request made by the Committee.

Please note the following conditions of approval:

- all Consent Forms and Information Sheets are to be printed on CSU letterhead. Students should liaise with their Supervisor to arrange to have these documents printed;
- you must notify the Committee immediately in writing should your research differ in any way from that proposed. You can do this on the form available at Faculty of Arts and Education website under the heading Finalising your project, requesting a variation or extension;
- you must notify the Committee immediately if any serious and or unexpected adverse events or outcomes occur associated with your research, that might affect the participants and therefore ethical acceptability of the project;
- amendments to the research design must be reviewed and approved by the Faculty Human Ethics Committee or if the project is no longer low risk research must be referred to the University Human Research Ethics Committee before commencement. Forms are available at the link above;
- if your research has not been completed by 4 September 2017, you are required to submit an extension request which will ensure your approval remains current. This form is at the above link;
- if your research has been completed by that date you are required to complete a Final Report form, which can be downloaded from the link above.

You are reminded that an approval letter from the HREC constitutes ethical approval only.

Importantly, if your research is being conducted in public schools you will need to seek SERAP approval from the Department of Education & Communities.

Please don’t hesitate to contact me if you have any inquiries about this matter.

Yours sincerely,

[Signature]
Professor Fran Press
telephone 02 6338 4297
temail FOAE-HREC@csu.edu.au
Arts and Education Faculty Human Ethics Committee

www.csu.edu.au
The Commonwealth Register of Institutions and Courses for Overseas Students (CRICOS) Provider Number for Charles Sturt University is 00013F. ABN: 13 414 805 488
Dear *****

Study 1 of the research project ‘Practices contributing to high STEM performance in rural Victorian government secondary schools’ has identified your school as a high STEM (Science, Technology, Engineering and Mathematics) performing school. This letter is an invitation for your school to be involved in Study 2 of the project which aims to study the practices that have contributed to rural school STEM success. Study 2 involves case studies of several rural Victorian government secondary schools identified as high STEM performing.

The study is being conducted by Mr. Steven Murphy, an experienced STEM teacher and school principal, from the School of Education at Charles Sturt University.

Research Team:
Chief Investigator:
Mr. Steven Murphy (M.Ed. B.Sc.) – Ph.D. Candidate, School of Education

Project Supervisors:
Dr. Lane Denaia, Lecturer – School of Teacher Education
Dr. Amy MacDonald, Senior Lecturer – School of Education
Dr. Cen (Audrey) Wang, Research Fellow – School of Teacher Education

1. What is the purpose of this study?
STEM skills and knowledge are seen as essential to thrive in our rapidly changing world. However, Australian students’ participation and achievement in STEM subjects have been decreasing over many years. Non-metropolitan or rural Australian students are six months or more even further behind in STEM achievement compared to students in major cities. Study 1 of this project has identified rural schools performing much better than average in STEM. Study 2 of this project researches the practices of these high STEM performing rural schools to find ways to improve STEM education for rural students.

2. Why has my school been invited to participate in this study?
Your school has been identified as high STEM performing compared to schools in similar locations and with similar SFOE indices.

3. What does this study involve?
If you agree for your school to participate the chief investigator will conduct two research visits to collect data for the case study. During these visits the chief investigator will:
- Collect school level data related to STEM performance, including VCE subject enrolment, and aggregated reporting data from the school level report.
- Take records of school facilities, particularly those related to STEM education.
- Collect samples of course outlines, newsletters, and other documents that provide evidence of practices impacting on your school’s STEM performance.
- Invite all teachers to participate in an online questionnaire (20 minutes) about their perception of the practices contributing to your school’s STEM performance.
- Conduct group interviews (30 minutes) with up to 10 Year 12 students about their experiences of STEM education at your school.
- Conduct one-on-one interviews (30 minutes) with the STEM leaders at your school exploring the implementation and impact of key practices contributing to your school’s STEM success.

Full details of the project can be found in the attached research proposal.
The chief investigator may also conduct other visits as you require, including to brief staff and students about the project and to share findings of the project.

4. Are there risks and benefits to my school in taking part in this study?
This research focuses on practices that have resulted in your school’s high STEM performance, so there will be an extremely low risk that any sensitive issues will be raised. All participants will be provided with information statements about their participation and will be required to give their written consent to participate. If any parts of the research cause participants discomfort or distress they may withdraw from the research at any time and without explanation. In these cases the researcher will work with the welfare supports of the school if anyone requires any support. We cannot promise your school any benefit from participating in this research. A written report and presentation about the findings of the research will be made available to the school at the conclusion of the research.

6. How is this study being paid for?
This research is paid for by the Chief Investigator’s Research Training Program scholarship.

6. Will taking part in this study cost my school anything?
Your school will not incur any fees through participation in this study. There will be a minor administrative burden associated with providing the research access to data, documents and facilities. Participation in the online questionnaire will cost volunteers between 20-30 minutes.

7. How will my school’s confidentiality be protected?
Pseudonyms will be used to protect the identity of your school and participants. Any information collected by the researchers which might identify your school will be stored securely and only accessed by the researchers and will not be discussed unless you consent otherwise, except as required by law. There are limits on assurances of confidentiality as law may subpoena research data/records. Data will be retained for at least 5 years at Charles Sturt University.

8. What will happen to the information collected from my school?
Your school’s data will be analysed along with data from several other high STEM performing rural schools as part of a multi-case study of high STEM performing rural schools. This study will form part of a thesis to be submitted for Mr Steven Murphy’s degree, and will also be published in papers in academic journals and presented at conferences. Schools will not be identified in any reports or publications arising from this project, without the written consent from the school and the Department of Education and Training. A summary report will be made available to all participants in this study.

9. What should I do if I want to discuss this study further before I decide?
Steven Murphy will contact you shortly to discuss this invitation with you. If you would like further information before then, please contact Steven Murphy on 0473 450 342 or at smurphy@csu.edu.au.

10. Who should I contact if I have concerns about the conduct of this study?
Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any comments or reservations about the ethical conduct of this project, you may contact the Committee on (02) 8338 4628 or ethics@csu.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Thank you for considering this invitation. I look forward to discussing it further with you soon,

Yours faithfully,

Steven Murphy
School location and socioeconomic status and patterns of participation and achievement in senior secondary mathematics

Steve Murphy

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Published online: 24 September 2018
© Mathematics Education Research Group of Australasia, Inc. 2018

Abstract
In many countries, there is pressure for schools to increase student engagement and skills in mathematics, in particular for disadvantaged students. This is certainly true in Australia. This study repurposes school level data to examine patterns of participation and achievement in senior secondary school mathematics in Victoria, Australia. It confirms that school socioeconomic status (SES) is strongly tied to participation and achievement in these subjects, and that nonmetropolitan schools tend to perform more poorly than metropolitan schools in these areas. It shows that nonmetropolitan schools are less likely to offer advanced mathematics subjects than metropolitan schools, and where they do, their students are less likely to choose those options. This study also reveals that correlations between mathematics performance and SES are far weaker in the nonmetropolitan school population than the metropolitan school population. This suggests that a nonmetropolitan location has a moderating effect on the impact of SES, pointing the way for potentially fruitful lines of future inquiry.

Keywords Mathematics - Achievement - Engagement - Equity - Disadvantage - Rural - Socioeconomic status

Introduction
In an increasingly technocentric world, it is argued that deep understanding of mathematics is a critical right for all, and there is a need to equip citizens with increasingly sophisticated mathematical skills (Center for Curriculum Redesign 2013). The rise of the Science, Technology, Education and Mathematics (STEM) movement over the past
decade has seen mathematics positioned as the essential foundation underpinning all aspects of STEM and contributing to the betterment of society (Office of the Chief Scientist 2013). STEM is seen as important for ensuring national security, economic growth, food and water supply and sustainable resource management, all in the face of a rapidly changing global environment. There is therefore a call to develop a workforce with strong STEM skills, particularly in mathematics and related fields such as data analysis, coding and engineering (Australian Industry Group 2015; Morgan and Kirby 2016).

However, as the global emphasis on mathematics has grown, achievement and participation in secondary school mathematics education in many countries have waned. The results of the Programme for International Student Assessment (PISA) revealed that 13 nations showed a significant decline in mathematics literacy from 2003 to 2015 while only six countries showed significant improvement (Thomson et al. 2017a). These results, as well as poor participation rates in senior mathematics and other STEM studies, have fuelled significant concerns in many English-speaking countries (Marginson et al. 2013). Further, significant equity issues are noted internationally in mathematics engagement and performance. On average, students from lower socioeconomic backgrounds report lower self-efficacy in mathematics the world over, and that self-efficacy correlates strongly with mathematical achievement (OECD 2013). The Trends in Mathematics and Science Study (TIMSS) shows that internationally, students attending schools with students from higher socioeconomic backgrounds had higher mathematics achievement (Mullis et al. 2013). The impact of socioeconomic status (SES) on mathematics achievement internationally is also reflected in PISA data (Kalaycioglu 2015).

Australia is one of the nations experiencing a decline in mathematics achievement and participation. Since 2003, the PISA reveals a downward trend in the mathematical literacy of Australian 15-year-olds, both relative to other nations and in absolute terms (Thomson et al. 2017a). Moreover, McPhan et al. (2008) point to a worrying trend of senior secondary students turning away from higher-level mathematics subjects, preferring instead to study the more basic mathematics courses. Australia also shows differences in the mathematical performance of students from families of different SES. PISA testing suggests that in Australia the difference between the average mathematical literacy scores of students from each SES quartile is the equivalent of approximately 1 year of schooling (Thomson et al. 2017a). A further equity issue apparent in Australia is disparity in mathematical achievement of students from different locations. PISA testing suggests that on average Australian students from metropolitan areas outperform students from nonmetropolitan areas by a year or more.

The present study sought to determine if similar patterns of inequity are seen in the participation and achievement of senior secondary students in mathematics in government secondary schools in Victoria, Australia. Further, it sought to explore any interactive effect of SES and location on mathematics participation and achievement. This study was part of a wider research programme repurposing enrolment and assessment data routinely collected from all government secondary schools offering the Victorian Certificate of Education (VCE) to measure the success of schools in various aspects of STEM education. Murphy (in press) presents findings from this programme as they relate to senior Science education. This paper focuses on mathematics education and addresses three research questions:
1. What is the relationship between school SES (the status of families sending children to the school) and student participation and achievement in senior secondary mathematics?
2. What is the relationship between the location of a school (metropolitan or non-metropolitan) and student participation and achievement in senior secondary mathematics?
3. Is there an interactive effect of socioeconomic status and location on student participation and achievement in senior secondary mathematics?

**Literature review**

This study positions both senior school participation rates and academic achievement as measures of an Australian school’s success in mathematics education. It then considers the impact of two contextual factors that research suggests impacts these metrics: school SES, and school location.

**Mathematics achievement and participation**

Both international and national testing raise concerns about the mathematical literacy of Australian students. The TIMSS shows that Australian year 8 students’ achievement in mathematics did not improve significantly from 1995 to 2015 (Thomson et al. 2017b). In contrast, of the 16 other countries with TIMSS data for the same period, nine showed significant improvement in mathematics achievement, four (including Australia) showed no improvement and three showed decreases. PISA mathematical literacy testing describes a similarly worrying story. In 2003, Australian year 9 students scored an average of 524 points in mathematical literacy performance, 25 points above the OECD average; however, in 2015 this score had shrunk to 494, only four points ahead of the OECD average (Thomson et al. 2017a). Australia’s own National Assessment Program—Literacy and Numeracy (NAPLAN) also suggests a stagnation in the numeracy performance of Australian secondary school students (Australian Curriculum Assessment and Reporting Authority 2017). At a time when mathematics is being internationally positioned as fundamental to innovation and development, Australian secondary students’ lack of growth in mathematical ability is particularly concerning.

Parallel to the issue of achievement are problems of participation in senior mathematics. From 1995 to 2010 there was a steady decrease in the number of year 12 students enrolling in intermediate or advanced mathematics, with a concomitant increase in the numbers enrolling in elementary mathematics subjects (Office of the Chief Scientist 2012). This trend has continued well into this decade (Barrington and Evans 2016; Kennedy et al. 2014). This shift is not limited to Australia, with other countries, including the USA, experiencing similar changes in participation in senior secondary mathematics (Marginson et al. 2013). McPhan et al. (2008) explored the reasons behind this shift in participation, suggesting that student experience in junior secondary mathematics, student self-efficacy in mathematics and student knowledge of careers involving advanced mathematics are among the most significant influences on student uptake of senior school mathematics. Further, research demonstrates that student engagement with mathematics deteriorates significantly in early secondary school.
Combined, this suggests that secondary schools have the opportunity and potential to address this concerning shift in participation in senior mathematics.

**SES and mathematics**

The 2015 PISA testing showed year 9 students from the highest SES quartile were on average 3 years ahead of those from the lowest SES quartile (Thomson, De Bortoli, et al. 2017). The TIMSS uses several indicators of SES, including the number of books in the home, the education resources in the home and the educational level of parents, and found that all three correlated strongly with achievement (Thomson et al. 2017a). A similar association between SES and achievement was revealed through the National Assessment Programme’s (NAP) numeracy testing. Year 9 students achieve better in numeracy testing if their parents have higher levels of education and if their parents work in higher occupation levels (Australian Curriculum Assessment and Reporting Authority 2017). These findings reflect the relationship between SES and mathematics achievement that has been well-researched internationally (Grootenboer and Hemmings 2007; Kalaycioglu 2015; Rothman 2003; Weber et al. 2010).

Not only does SES correlate with achievement, it also impacts on student participation in mathematics. As parental education and occupation levels increase, so does the number of students enrolling in advanced mathematics courses (McPhan et al. 2008). Studies shed some light on why SES may have this impact by considering engagement with mathematics in the early years of secondary schooling. TIMSS attitudinal surveying shows that by year 8, lower SES students report not liking learning mathematics in significantly higher proportions than other students. PISA measurements of student motivation to learn and succeed in mathematics suggest that year 9 students from high SES backgrounds were far more motivated to achieve in mathematics than other students. Martin et al. (2013) suggest that students from lower SES schools are more likely to self-handicap, become disengaged and to have reduced class participation in mathematics.

**Location and mathematics**

International and national testing also suggests that school location correlates with mathematics achievement in Australia. The TIMSS demonstrates that metropolitan year 8 students significantly outperform students from provincial schools who, in turn, outperform students from remote areas (Thomson et al. 2017b). PISA testing shows metropolitan year 9 students’ mathematical literacy is significantly higher than the OECD average and nonmetropolitan year 9 students’ is significantly lower, with the gap between the two being the equivalent of more than a year of learning (Thomson et al. 2017a). This pattern is also borne out by national numeracy testing (Australian Curriculum Assessment and Reporting Authority 2017).

This author was unable to locate studies comparing participation rates in mathematics by remoteness. The link between mathematics engagement and school remoteness has been explored but this does not suggest a definitive relationship. PISA testing shows that relationship between motivation and remoteness is not linear, suggesting that rural students have the highest motivation to learn mathematics, followed by
metropolitan students, with provincial students testing as having the lowest motivation (Thomson et al. 2013). Harde (2011) reviews the scant international research into student motivation in mathematics in rural schools and presents conflicting evidence, with some studies suggesting high motivation in mathematics in rural settings, while other studies found low motivation.

**Method**

This paper presents analyses of patterns of participation and achievement in mathematics subjects offered within the VCE. The VCE is designed to be completed over 2 years, and is made up of semester-long units of study, with unit 1 and unit 2 studies benchmarked at a year 11 level and unit 3 and unit 4 studies benchmarked at a year 12 level (Victorian Curriculum and Assessment Authority 2017). Students are awarded the VCE after completing a minimum of 16 units, including three English units and three unit 3–4 sequences in addition to English. However, students typically complete more units than this, with most schools encouraging students to take 12 units at year 11 level and 10 units at year 12 level. Year 11 level units are assessed only as satisfactory or unsatisfactory. Year 12 level units allow students to earn a study score by completing a combination of school-based and external assessments, for year 12 level units. These study scores are used to determine a student’s Australian Tertiary Admission Rank (ATAR) which Australian tertiary institutions use as a key element of their candidate selection process for most of their courses.

Studying mathematics is not compulsory to earn a VCE. There are several mathematics subjects on offer in the VCE and students may elect to take none, one, or more of these (Victorian Curriculum and Assessment Authority 2016). Foundation Mathematics units 1 and 2 are for students not intending to study mathematics at a year 12 level. General Mathematics units 1 and 2 and Further Mathematics units 3 and 4 are designed to be widely accessible. Both of these involve the study of non-calculus-based topics such as geometry, statistics and algebra. Mathematical Methods units 1–4 involve more advanced mathematics, including the study of calculus, probability and statistics. Specialist Mathematics units 1–4 are the most advanced mathematics subjects offered in the VCE. They are designed to be taken in conjunction with Mathematical Methods, extending its content to look at topics such as complex numbers, vectors and statistical inference. Expected pathways of mathematical units that students may study are shown in Table 1. While many university courses recommend that students complete a mathematics subject at year 12 level, only Mathematical Methods Unit 3–4 and Specialist Mathematics units 3–4 are ever listed explicitly by any Victorian tertiary institution as a possible prerequisite for entry into any of their courses (Victorian Tertiary Admissions Centre 2016). In this paper, these two mathematics subjects are discussed as the ‘enabling mathematics subjects’.

**Study data**

Location and demographic information, VCE mathematics enrolment numbers and median study scores in mathematics subjects were obtained for every Victorian government school offering a VCE program from 2014 to 2016 (N = 286). This school
Table 1  Expected pathways of VCE mathematics units

<table>
<thead>
<tr>
<th>Year 11 level (units 1 and 2)</th>
<th>Year 12 level (units 3 and 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation Mathematics</td>
<td></td>
</tr>
<tr>
<td>Foundation Mathematics plus supplementary study; or</td>
<td>leads to Further Mathematics</td>
</tr>
<tr>
<td>General Mathematics</td>
<td></td>
</tr>
<tr>
<td>Mathematical Methods; or</td>
<td>leads to Mathematical Methods and/or Further Mathematics</td>
</tr>
<tr>
<td>General Mathematics and Further Mathematics</td>
<td></td>
</tr>
<tr>
<td>Mathematical Methods plus supplementary study; or</td>
<td>leads to Mathematical Methods and Specialist Mathematics</td>
</tr>
<tr>
<td>Mathematical Methods and General Mathematics; or</td>
<td></td>
</tr>
<tr>
<td>Mathematical Methods and Specialist Mathematics</td>
<td></td>
</tr>
</tbody>
</table>

level data is routinely collected by the Victorian Department of Education and Training (DET) and was shared with the author in a de-identified form. Sampling across these three recent years mitigates against cohort effects, while also producing contemporary baseline findings on which to base future comparisons. Cohort effects are especially likely in rural schools with small numbers of students completing the VCE.

Outcome variables

Schools from different locations and serving communities of different socioeconomic status were compared using three outcome variables: subjects provided, enrolment proportion and achievement level.

Subjects provided

The Subjects Provided variable tracks which of the four year 11 and three year 12 mathematics subjects any particular school had students studying across 3 years (2014–2016).

Enrolment proportions

Enrolment proportions for each mathematics subject were calculated for each school delivering that subject by dividing the number of enrolments in a particular mathematics unit by the total number of VCE enrolments at that particular level and then averaging this result across the three years (2014–2016). It should be noted that it is likely that some students may have enrolled in more than one mathematics subject; however, there is no way to identify this in the data used for this analysis.

Achievement levels

Study scores are only available for the year 12 subjects so achievement levels were calculated only for each year 12 subject. They were calculated for each school running a particular subject in all three years (2014, 2015 and 2016) by averaging the median school year 12 study score from each of the three years. Study scores have been
standardised by the VCAA to allow them to be compared from school to school and year to year. This is done by first ranking each student’s performance against all others in that subject in that year. Students are then allocated study scores according to their rank so that the distribution of scores is normalised, with a maximum of 50, a set mean of 30 and standard deviation of 7 (Victorian Curriculum and Assessment Authority 2017).

Explanatory variables

Two explanatory variables are considered in this study; student family occupation and education index (SFOE) and school location.

Student family occupation and education index

Student family occupation and education index (SFOE) is calculated for each school by DET using both parental education levels and occupation categories as recorded in school enrolment details. SFOE is a measure of socioeconomic disadvantage, where the higher the SFOE, the lower the SES, and the greater the disadvantage of families at the school (Department of Education and Training 2016). In some analyses, the SFOE is analysed in quartiles, with the first SFOE quartile including the highest SES schools and the fourth SFOE quartile the lowest SES schools.

School location

Schools were categorised as either metropolitan (N = 164), if located in a local government area (LGA) within the Greater Melbourne area, or nonmetropolitan (N = 122), if located in a LGA in any other region in Victoria (Victorian Government 2017). This coarse granularity of location categories was a limitation of the de-identified data used in this study. Consequently, schools classified as nonmetropolitan include schools in regional cities as well as rural and remote locations.

The distribution of schools by SFOE and school location is shown in Table 2.

Analysis

As this study used data from the entire population of interest, sampling error was not a risk and therefore calculations of statistical significance were not required. The focus was on the practical significance of the statistics only (Cohen et al. 2011).

Table 2 Distribution of schools by SFOE and school location

<table>
<thead>
<tr>
<th>School location</th>
<th>Quartile 1</th>
<th>Quartile 2</th>
<th>Quartile 3</th>
<th>Quartile 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropolitan schools</td>
<td>61</td>
<td>28</td>
<td>29</td>
<td>46</td>
<td>164</td>
</tr>
<tr>
<td>Nonmetropolitan schools</td>
<td>11</td>
<td>42</td>
<td>43</td>
<td>25</td>
<td>122</td>
</tr>
<tr>
<td>Total</td>
<td>72</td>
<td>71</td>
<td>72</td>
<td>71</td>
<td>286</td>
</tr>
</tbody>
</table>
Descriptive statistics were used to summarise patterns of participation and achievement in mathematics subjects across location and SES categories. The proportions of schools providing the different mathematics subjects, and the means and ranges of enrolment proportions, and the achievement levels in the year 12 subjects, were compared by school location and SFOE quartile. The relationships between both enrolment proportions, achievement level, and SFOE were further investigated using Spearman’s rho correlation coefficients. Coefficients were calculated for all schools, for metropolitan schools and for nonmetropolitan schools respectively to examine differences in these relationships based on location.

Results

VCE mathematics subjects provided

Table 3 shows that almost all schools provided General Mathematics and Mathematical Methods at year 11 level, and Further Mathematics and Mathematical Methods at year 12 level, independent of location. It shows that nonmetropolitan schools were slightly more likely than metropolitan schools to run year 11 Foundation Mathematics, but far less likely to run year 11 or year 12 Specialist Mathematics.

Table 4 shows the lowest SES schools were more likely to offer year 11 Foundation Mathematics than the highest SES schools. The inverse is true for Specialist Mathematics, with the highest SES schools running this subject in far higher proportions than the lowest SES schools at both year 11 and 12 levels.

Enrolment proportions

Table 5 shows that the enrolment proportion for each of the VCE mathematics subjects varies with location. Enrolment proportions are only calculated using data from schools providing each subject. Table 5 shows the enrolment proportion for the year 11 level subjects of Foundation Mathematics and General Mathematics is slightly higher in nonmetropolitan schools compared to metropolitan schools. It also shows that

<table>
<thead>
<tr>
<th></th>
<th>Metropolitan schools (N = 164)</th>
<th>Non-metropolitan schools (N = 122)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 Foundation Mathematics</td>
<td>53%–59%</td>
<td>57%–62%</td>
</tr>
<tr>
<td>Year 11 General Mathematics</td>
<td>98%–99%</td>
<td>99%–100%</td>
</tr>
<tr>
<td>Year 12 Further Mathematics</td>
<td>96%–98%</td>
<td>98%–99%</td>
</tr>
<tr>
<td>Year 11 Mathematical Methods</td>
<td>97%–100%</td>
<td>96%–98%</td>
</tr>
<tr>
<td>Year 12 Mathematical Methods</td>
<td>95%–98%</td>
<td>89%–93%</td>
</tr>
<tr>
<td>Year 11 Specialist Mathematics</td>
<td>63%</td>
<td>34%</td>
</tr>
<tr>
<td>Year 12 Specialist Mathematics</td>
<td>72%–80%</td>
<td>51%–53%</td>
</tr>
</tbody>
</table>

*a Year 11 Specialist Mathematics was only offered in 2016
nonmetropolitan schools have a slightly higher enrolment proportion for year 12 level Further Mathematics than metropolitan schools. However, in the enabling subjects, the pattern is reversed with the enrolment proportion in year 11 Mathematical Methods being greater in metropolitan schools than nonmetropolitan schools. This gap widens further for year 12 Mathematical Methods. The enrolment proportion in the recently introduced year 11 Specialist Mathematics is greater in metropolitan schools than nonmetropolitan schools. This gap widens for year 12 Specialist Mathematics.

Table 6 shows that the enrolment proportion for each of the VCE mathematics subjects varies with SES. The proportion of enrolments for year 11 General Mathematics and year 12 Foundation Mathematics are slightly lower in the highest SES schools (1st SFOE quartile) compared to all other schools. However, the enrolment proportion for year 11 Foundation Mathematics in the lowest SES schools is nearly twice that of the enrolment proportion in the highest SES schools. This trend is reversed for the uptake of Mathematical Methods and Specialist Mathematics. The highest SES schools have greater enrolment proportions in all both enabling mathematics studies at year 11 and year 12 levels, compared to the lower SES schools.

The relationship between SFOE and enrolment proportions was investigated by calculating Spearman’s rho correlation coefficients for each subject across all schools, metropolitan schools and nonmetropolitan schools. It should be noted, as SFOE is a measure of disadvantage a negative correlation indicates a positive relationship.
Table 5  Enrolments in VCE mathematics subjects as a proportion of all VCE subject enrolments by school location

<table>
<thead>
<tr>
<th></th>
<th>All schools</th>
<th>Metropolitan schools</th>
<th>Nonmetropolitan schools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (range)</td>
<td>Mean (range)</td>
<td>Mean (range)</td>
</tr>
<tr>
<td>Year 11</td>
<td>0.028</td>
<td>0.027</td>
<td>0.030</td>
</tr>
<tr>
<td>Foundation Mathematics</td>
<td>(0.000–0.112)</td>
<td>(0.000–0.112)</td>
<td>(0.000–0.083)</td>
</tr>
<tr>
<td>Year 11</td>
<td>0.106</td>
<td>0.160</td>
<td>0.115</td>
</tr>
<tr>
<td>General Mathematics</td>
<td>(0.005–0.196)</td>
<td>(0.005–0.177)</td>
<td>(0.058–0.196)</td>
</tr>
<tr>
<td>Year 12</td>
<td>0.122</td>
<td>0.114</td>
<td>0.133</td>
</tr>
<tr>
<td>Further Mathematics</td>
<td>(0.008–0.200)</td>
<td>(0.008–0.171)</td>
<td>(0.071–0.200)</td>
</tr>
<tr>
<td>Year 11</td>
<td>0.051</td>
<td>0.057</td>
<td>0.045</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>(0.004–0.172)</td>
<td>(0.007–0.172)</td>
<td>(0.004–0.103)</td>
</tr>
<tr>
<td>Year 12</td>
<td>0.045</td>
<td>0.051</td>
<td>0.037</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>(0.004–0.155)</td>
<td>(0.004–0.155)</td>
<td>(0.004–0.103)</td>
</tr>
<tr>
<td>Year 11</td>
<td>0.007</td>
<td>0.008</td>
<td>0.005</td>
</tr>
<tr>
<td>Specialist Mathematics</td>
<td>(0.000–0.097)</td>
<td>(0.000–0.097)</td>
<td>(0.000–0.026)</td>
</tr>
<tr>
<td>Year 12</td>
<td>0.014</td>
<td>0.017</td>
<td>0.010</td>
</tr>
<tr>
<td>Specialist Mathematics</td>
<td>(0.001–0.075)</td>
<td>(0.001–0.075)</td>
<td>(0.001–0.028)</td>
</tr>
</tbody>
</table>

between SES and enrolment proportions. As can be seen in Table 7, there is a weak positive correlation between SFOE and enrolment proportions in year 11 Foundation Mathematics ($\rho = 0.24$), and a moderate positive correlation in year 12 Further Mathematics ($\rho = 0.34$). However, there is a moderate negative correlation between SFOE

Table 6  Enrolments in VCE mathematics subjects as a proportion of all VCE subject enrolments by SFOE quartile

<table>
<thead>
<tr>
<th></th>
<th>1st quartile SFOE schools (highest SES)</th>
<th>2nd quartile SFOE schools</th>
<th>3rd quartile SFOE schools</th>
<th>4th quartile SFOE schools (lowest SES)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean (range)</td>
<td>mean (range)</td>
<td>mean (range)</td>
<td>mean (range)</td>
</tr>
<tr>
<td>Year 11</td>
<td>0.018 (0.006–0.072)</td>
<td>0.028 (0.005–0.058)</td>
<td>0.029 (0.001–0.112)</td>
<td>0.025 (0.000–0.066)</td>
</tr>
<tr>
<td>Foundation Mathematics</td>
<td>0.095 (0.057–0.158)</td>
<td>0.108 (0.005–0.180)</td>
<td>0.114 (0.051–0.171)</td>
<td>0.109 (0.020–0.196)</td>
</tr>
<tr>
<td>Year 12</td>
<td>0.010 (0.026–0.169)</td>
<td>0.017 (0.008–0.200)</td>
<td>0.133 (0.086–0.191)</td>
<td>0.125 (0.039–0.181)</td>
</tr>
<tr>
<td>Further Mathematics</td>
<td>0.074 (0.012–0.172)</td>
<td>0.049 (0.007–0.099)</td>
<td>0.042 (0.017–0.096)</td>
<td>0.041 (0.004–0.092)</td>
</tr>
<tr>
<td>Year 11</td>
<td>0.064 (0.012–0.155)</td>
<td>0.040 (0.004–0.098)</td>
<td>0.037 (0.004–0.105)</td>
<td>0.039 (0.004–0.094)</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>0.010 (0.01–0.037)</td>
<td>0.004 (0.001–0.013)</td>
<td>0.006 (0.001–0.013)</td>
<td>0.006 (0.001–0.017)</td>
</tr>
<tr>
<td>Year 12</td>
<td>0.022 (0.001–0.075)</td>
<td>0.011 (0.002–0.030)</td>
<td>0.009 (0.001–0.024)</td>
<td>0.014 (0.002–0.055)</td>
</tr>
</tbody>
</table>
Table 7  Spearman’s rho correlation coefficients for SFDE and VCE mathematics subject enrolment proportions by all schools, metropolitan schools and nonmetropolitan schools

<table>
<thead>
<tr>
<th></th>
<th>All schools rho (N)</th>
<th>Metropolitan schools rho (N)</th>
<th>Nonmetropolitan schools rho (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 Foundation Mathematics</td>
<td>0.24 (204)</td>
<td>0.24 (113)</td>
<td>0.22 (91)</td>
</tr>
<tr>
<td>Year 11 General Mathematics</td>
<td>0.19 (286)</td>
<td>0.28 (164)</td>
<td>0.01 (122)</td>
</tr>
<tr>
<td>Year 12 Further Mathematics</td>
<td>0.24 (284)</td>
<td>0.50 (162)</td>
<td>0.02 (122)</td>
</tr>
<tr>
<td>Year 11 Mathematical Methods</td>
<td>−0.47 (285)</td>
<td>−0.51 (164)</td>
<td>−0.43 (121)</td>
</tr>
<tr>
<td>Year 12 Mathematical Methods</td>
<td>−0.36 (289)</td>
<td>−0.40 (162)</td>
<td>−0.26 (118)</td>
</tr>
<tr>
<td>Year 11 Specialist Mathematics</td>
<td>−0.38 (145)</td>
<td>−0.47 (103)</td>
<td>0.02 (42)</td>
</tr>
<tr>
<td>Year 12 Specialist Mathematics</td>
<td>−0.29 (227)</td>
<td>−0.33 (141)</td>
<td>−0.08 (86)</td>
</tr>
</tbody>
</table>

and enrolment proportions across all schools in year 11 Mathematical Methods ($\rho = -0.47$), a weaker moderate negative correlation in year 11 Specialist Mathematics ($\rho = -0.38$) and year 12 Mathematical Methods ($\rho = -0.36$) and a weak negative correlation in year 12 Specialist Mathematics ($\rho = -0.29$). However, when calculating coefficients using data from only metropolitan schools, the strength of all of these correlations increases. Conversely, in nonmetropolitan schools, these correlations weaken significantly, with most becoming negligible.

**Achievement level**

Table 8 shows that achievement levels in each of the VCE mathematics subjects varies with location. Metropolitan schools outperform nonmetropolitan schools in all three year 12 VCE mathematics subjects. Metropolitan schools’ average (mean) study scores are 9.83, 1.67 and 1.82 points higher than that of nonmetropolitan schools’ in Further Mathematics, Mathematical Methods and Specialist Mathematics respectively. This table also flags a further equity issue. As the mean for each VCE subject is fixed at 30 and the means reported in this table are well below this, it points to the disparity of average achievement of students attending government schools compared to those enrolled at independent schools.

Table 8  Comparison of schools’ median achievement levels in VCE year 12 mathematics subjects, where results were available for 2014, 2015 and 2016, by location

<table>
<thead>
<tr>
<th></th>
<th>All schools</th>
<th>Metropolitan schools</th>
<th>Nonmetropolitan schools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (range)</td>
<td>N</td>
</tr>
<tr>
<td>Further Mathematics</td>
<td>222</td>
<td>27.97 (18.36–41.21)</td>
<td>139</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>221</td>
<td>26.57 (16.96–37.32)</td>
<td>139</td>
</tr>
<tr>
<td>Specialist Mathematics</td>
<td>222</td>
<td>26.66 (17.03–46.00)</td>
<td>139</td>
</tr>
</tbody>
</table>

()} Springer
Table 9  Comparison of schools’ achievement levels in VCE year 12 mathematics subjects, where results were available for 2014, 2015 and 2016, by SFOE quartile

<table>
<thead>
<tr>
<th>Subject</th>
<th>1st quartile SFOE schools (highest SES)</th>
<th>2nd quartile SFOE schools</th>
<th>3rd quartile SFOE schools (lowest SES)</th>
<th>4th quartile SFOE schools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Further Mathematics</td>
<td>68</td>
<td>54</td>
<td>53</td>
<td>47</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>68</td>
<td>54</td>
<td>53</td>
<td>47</td>
</tr>
<tr>
<td>Specialist Mathematics</td>
<td>68</td>
<td>54</td>
<td>53</td>
<td>47</td>
</tr>
</tbody>
</table>

Table 9 also shows that achievement levels in each of the VCE mathematics subjects also vary with SFOE. Year 12 VCE mathematics performance decreases across the SFOE quartiles in all three subjects. In Further Mathematics, Mathematical Methods and Specialist Mathematics, first quartile SFOE schools’ average study scores are 4.52, 4.55 and 2.54 points higher than that of fourth quartile schools in these subjects respectively.

The relationship between SFOE and achievement level was investigated by calculating Spearman’s rho correlation coefficients for each subject, across all schools, metropolitan schools and nonmetropolitan schools respectively. Again, note that as SFOE is a marker of disadvantage, a negative correlation indicates a positive relationship between SES and enrolment proportions. As can be seen in Table 10, there is a moderate negative correlation between SFOE and achievement across all schools in Further Mathematics ($\rho = -0.496$) and Mathematical Methods ($\rho = -0.482$), and a weaker moderate negative correlation in Specialist Mathematics ($\rho = -0.390$). However, when calculating coefficients using data from only metropolitan schools, the strength of these correlations increases, with strong negative correlations observed between SFOE and achievement in Further Mathematics ($\rho = -0.611$) and Mathematical Methods ($\rho = -0.613$), and a moderate negative correlation in Specialist Mathematics ($\rho = -0.453$). Conversely, in nonmetropolitan schools there is only a weak negative correlation between SFOE and achievement in Further Mathematics ($\rho = -0.255$) and Specialist Mathematics ($\rho = -0.242$), and a negligible correlation in Mathematical Methods ($\rho = -0.193$).

Table 10  Spearman’s rho correlation coefficients for SFOE and VCE Year 12 mathematics subject achievement levels for all schools, metropolitan schools and nonmetropolitan schools

<table>
<thead>
<tr>
<th>Year 12 Subject</th>
<th>All schools rho ($N$)</th>
<th>Metropolitan schools rho ($N$)</th>
<th>Nonmetropolitan schools rho ($N$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 12 Further Mathematics</td>
<td>-0.496 (284)</td>
<td>-0.611 (162)</td>
<td>-0.255 (122)</td>
</tr>
<tr>
<td>Year 12 Mathematical Methods</td>
<td>-0.482 (286)</td>
<td>-0.613 (162)</td>
<td>-0.193 (118)</td>
</tr>
<tr>
<td>Year 12 Specialist Mathematics</td>
<td>-0.390 (226)</td>
<td>-0.453 (141)</td>
<td>-0.242 (85)</td>
</tr>
</tbody>
</table>
Discussion

This study set out to explore the impact of school SES and school location on participation and achievement in VCE mathematics subjects in Victorian government schools. To do this, it used de-identified data from all Victorian government secondary schools offering a VCE mathematics subject across the three years of 2014, 2015 and 2016. Three outcome variables were examined: the VCE mathematics subjects provided by each school, each school’s proportional enrolments in each mathematics subject (as a proportion of all VCE subject enrolments) and the average achievement levels of students completing VCE mathematics subjects at year 12 level in each school.

Some findings from this study demonstrated the patterns of participation and achievement in mathematics in the Victorian government sector are consistent with the literature. On average, students from lower SES schools were less likely to have access to higher level mathematics subjects, were less likely to enrol in these subjects and achieved less well in these subjects, compared with students attending higher SES schools. Students from lower SES schools were more likely to enrol in the less challenging VCE mathematics subjects, however they still achieved less well than their high SES counterparts. Rothman (2003) noted similar findings, suggesting significant effects of SES between schools on numeracy achievement. Metropolitan schools achieved better results on average than schools outside the greater Melbourne metropolitan area, mirroring the findings of previous studies of geographic location on the mathematical literacy of secondary school students (Australian Curriculum Assessment and Reporting Authority 2017; Thomson et al. 2017b).

Other findings contribute new knowledge to the field. This study found that students in nonmetropolitan schools were more likely than metropolitan students to enrol in foundational mathematics subjects at years 11 and 12. Conversely, they were less likely to have access to the enabling mathematics subjects, and where they did have access, they were less likely to enrol in those subjects.

Perhaps, more revelatory is that the current study suggests that a nonmetropolitan location has a moderating effect on the influence of school SES. As school family disadvantage increases in Metropolitan schools, participation in challenging mathematics and achievement levels in all mathematics tends to decrease. This is unsurprising given research consistently finds a negative correlation between SES and student mathematics engagement and achievement (Vale et al. 2016). However, in nonmetropolitan schools, SES in this study appeared to have little to no impact on mathematics subjects offered, the proportions of students enrolling in mathematics, or average achievement levels in mathematics. Importantly, some nonmetropolitan schools dramatically outperformed others independent of the background of their students’ families. In other words, while the nonmetropolitan schools on average underperformed in relation to the metropolitan schools, their performance was varied and SES did not appear to explain that variability.

So, what are the factors independent of SES, influencing nonmetropolitan school performance in the enabling mathematics? Past research hints at possible explanations. Many researchers (Lyon et al. 2006; Margison et al. 2013; Weldon 2016) highlight the difficulties of recruiting qualified mathematics teachers to rural and remote areas, and of providing these teachers with quality professional development. Without quality mathematics teachers, schools may not be able to offer the more advanced mathematics
courses, let alone attract students to enrol in them or adequately prepare students to perform well. McPhan et al. (2008) identified student reticence to participate in composite and distance classes in rural schools as a reason why students do not take up advanced senior mathematics classes, and participating in such class formats may go some way in explaining the lower mathematics achievement levels of students in some nonmetropolitan schools. Other authors have suggested that rural students (and their parents) have lower expectations of continuing on to tertiary study (Centre for Education Statistics and Evaluation 2013), so they may be less motivated to participate and achieve in enabling mathematics subjects. However, while this research may help explain why country schools tend to perform less well in senior mathematics than their city cousins, it does not explain why some nonmetropolitan schools perform unexpectedly well.

Existing research suggests few possible explanations for this aberrant excellence in mathematics. Some research suggests that strong family-school connections and supportive relationships with school communities can positively affect the educational outcomes of rural students (Barley and Beesley 2007; Harde 2011; Semke and Sheridan 2012). Possibly, the high-performing nonmetropolitan schools identified in the current study have been able to capitalise upon their location and perhaps smaller size to better foster such relationships. Related to this may be that some nonmetropolitan schools are better able to make use of rich local community resources afforded nonmetropolitan schools, such as agriculture, industry and the natural environment, to provide relevant contexts for mathematics learning, thus improving student engagement and achievement.

Whatever the explanation, these findings have concerning practical implications for students attending our low SES and nonmetropolitan schools. Low participation and achievement in enabling mathematics subjects mean that many students from these schools are automatically ruled out of access to some tertiary courses in engineering, computer science and biomedical science (Victorian Tertiary Admissions Centre 2016), all of which lead to careers with growing demand for workers (Australian Industry Group 2015).

This study repurposed school level data from the Victorian DET to uncover broad patterns of participation and achievement in the enabling mathematics subjects and to set a baseline for future research. As such, it does not reveal anything of the role student characteristics, such as gender, indigeneity or ethnicity, may have in moderating the relationships observed in this study, yet these variables are likely to inter-relate with the variables discussed in this paper (Thomson et al. 2017a). Further, while this study reveals relationships between school SES and location and mathematics participation and achievement, the data analysed in this study do not explain why these relationships exist.

The findings highlight the need for further research in a range of areas. It needs to be explored why lower SES schools are less likely to offer the enabling mathematics subjects. Research is also needed to understand why nonmetropolitan students are less likely to enrol in the more challenging mathematics subjects, as the current research offers no conclusive findings around remoteness and engagement (Harde 2011). While the impact of SES and remoteness on achievement in mathematics is well described in the literature, the findings presented in this paper suggests that location has a moderating effect on the impact of SES. There needs to be more research to understand this
relationship. This research also identifies an opportunity to explore why some nonmetropolitan schools perform much better than expected in mathematics education. Such investigation promises to not only provide a model for improving mathematics education in other nonmetropolitan schools, but it could also identify ways in which metropolitan schools might minimise the influence of disadvantage. Case studies should be made of high-performing nonmetropolitan schools at all SES levels, with particular focus on staffing, resourcing, community connection and student and parent expectations. This research could help identify positive school leadership and mathematics education practices for other schools to consider.

Conclusion

This research confirms that the socioeconomic status of the community a school serves impacts on participation and achievement levels in senior mathematics in Victorian secondary schools. This impact is most prominent in the more challenging mathematics subjects which are the same subjects often required for entry into tertiary courses in engineering, computer science, biomedical science and the like. As could be anticipated from previous research, nonmetropolitan schools on average underperformed in comparison to metropolitan schools in mathematics achievement. This study did however reveal that non-metropolitan students are less likely to participate in enabling mathematics subjects and are more likely to take elementary mathematics subjects, than their metropolitan counterparts. Further, this study shows that schools in nonmetropolitan locations somehow largely mitigate against the effects of SES. Importantly, this study reveals there are schools in each SES category that perform notably better than their counterparts, providing potential exemplar case studies for research aimed at addressing the inequities exposed in this paper.

References


School location and socioeconomic status and patterns of participation and achievement in senior secondary mathematics. Murphy.

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The Impact of School Disadvantage on Senior Secondary Science: a Study of Patterns of Participation and Achievement in Government Secondary Schools in Victoria, Australia

Steve Murphy

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Abstract Science and science education are recognised internationally as essential for ensuring a sustainable and prosperous future. At the same time, significant equity issues are apparent in science education. This study used enrolment and academic result data, routinely collected from government schools in Victoria, Australia, to examine the impact of socioeconomic status and school location on patterns of participation and achievement in senior school Biology, Chemistry, Environmental Science, Physics and Psychology. This research shows that though non-metropolitan students are less likely to have the sciences provided by their school, where they are provided they enrol in similar proportions to metropolitan students. In line with other research, it shows that high SES students are more likely than other students to study senior secondary Chemistry and Physics, and outperform low SES students in all senior sciences. While the findings of this study suggest that non-metropolitan students underperform their metropolitan counterparts in senior sciences, they suggest the gap in performance is not dramatic. More promising, the variation in school performance revealed in this study suggests that non-metropolitan schools can achieve just as well as metropolitan schools in the sciences. The study also suggests location has a moderating effect on SES not noted in the current literature, where science achievement in non-metropolitan schools appears less impacted upon by SES than similar schools in urban environments. This provides impetus for further research into high science performing non-metropolitan schools as a step towards addressing some of the equity concerns in science education.

Keywords Science education · Secondary school · Equity · Socioeconomic status · Rural education

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Introduction

Internationally, science and science education are seen as key factors for a sustainable world, where food and water supplies are secure, good health is assured and our climate and biodiversity is preserved (UNESCO 2017). Further, science literacy, for all citizens, is seen as essential for prosperity and economic growth (OECD 2018). Australia reflects these international trends through the widespread and vigorous backing of the Science, Technology, Engineering and Mathematics (STEM) movement in recent years. Australian governments and businesses alike position science and STEM as key to the betterment of Australian society and to ensuring national security and economic competitiveness (Australian Industry Group 2015; Department of the Prime Minister and Cabinet 2015; Office of the Chief Scientist 2013).

While there is significant international emphasis on the importance of science education, the Programme for International Students Assessment (PISA) suggests that for most countries, science performance has not improved from 2006 to 2015 (OECD 2018). Unfortunately for Australia, the situation is worse, with PISA testing suggesting that the scientific literacy of year 9 students has in fact declined over the past decade (Thomson et al. 2017a). Not only are there concerns about science performance internationally, many countries have concerns about declining enrolments in senior secondary school science subjects, including the USA and UK (Cooper et al. 2018). Again, Australia does not buck this trend with participation rates in year 12 sciences in Australian secondary schools being the lowest they have been for decades (Office of the Chief Scientist 2017).

There are also significant equity concerns regarding scientific literacy in many countries, including Australia. Across the OECD, year 9 students of lower socioeconomic status (SES) perform worse in scientific literacy than higher SES students (OECD 2018). In Australia, the gap between the scientific literacy of students from the highest SES quartile to the lowest SES quartile is equivalent to approximately three years of schooling (Thomson et al. 2017a). Further, where a student lives appears to impact their scientific literacy. Year 9 Australian students attending metropolitan schools outperform students from non-metropolitan areas by at least one year (Thomson et al. 2017a).

While the links between general science achievement and SES and, to a lesser degree, location have been explored in Australia (for example, Thomson et al. 2017b), minimal attention has been given to this relationship at the level of the individual senior science subjects. Also, participation rates in Australian school science have been examined at the level of the separate science subjects (cf. Kennedy et al. 2014); however, there has been little research into the impact of SES and location on these participation rates. This study addressed these gaps by investigating senior science subject participation and achievement, comparing patterns across the five Victorian Certificate of Education (VCE) science subjects available in Victoria, Australia. It identified potential inequities associated with SES and location, and sought to explore any interaction effect (Vogt 2005) between these variables on science participation and/or achievement. This paper asks three research questions:

1. What is the relationship between school SES (the aggregate socioeconomic status of students at the school) and student participation and achievement in VCE sciences?
2. What is the relationship between the location of a school (metropolitan or non-metropolitan) and student participation and achievement in the VCE sciences?
3. Is there an interaction effect of socio-economic status and location on student participation and achievement in the VCE sciences?
This study is part of a larger research project using aggregate enrolment and assessment data collected from all Australian Victorian government secondary schools offering the VCE to compare the success of schools in STEM education.

**Literature**

This study considers both senior school participation rates and academic achievement as measures of Australian school success in science education. It then examines the impact of two school-level contextual factors that research suggests impacts these metrics, school SES and school location.

**Science Achievement and Participation**

The progress of Australian students’ achievement in science appears to have stalled. The Trends in International Mathematics and Science Study (TIMSS) suggests that the science achievement of both year 4 and year 8 Australian students has not changed significantly in the past twenty years (Thomson et al. 2017b). This is while more participating countries have seen increases than decreases in science achievement at these year levels. International PISA testing shows that Australian year 9 students’ scientific literacy scores have fallen by 17 points from 2006 to 2015, while the average OECD score declined by only 5 points during the same time period (Thomson et al. 2017a). This lack of improvement in Australian student science achievement is also reflected in the results of the National Assessment Plan’s (NAP) science literacy assessment that suggest that year 6 students’ science literacy has not changed significantly in the past decade (Connolly 2017). It is interesting to note that there is scant research exploring science achievement in the final years of secondary school.

Not only has Australian students’ science performance not improved in the last 10 years, participation in senior science subjects has also declined (Cooper et al. 2018). Kennedy et al. (2014) report that from 1992 to 2012, participation rates in the traditional sciences of Biology, Chemistry and Physics fell by 10, 5 and 7% respectively. This study also showed that of these three subjects, Biology had the highest participation rates and Physics the lowest, with Chemistry participation rates closer to those of Physics than Biology. Further, this study reported on the participation rates of “Earth Sciences” which included Geology, Environmental Science, and Earth and Environmental Science, showing that these subjects had the lowest participation rates of the sciences; however, they were the only category with slightly increasing participation rates. Kennedy et al. (2014) did not report on participation in Psychology, due to some jurisdictions presenting this subject as a social science, and others not offering it at all. However, an earlier study by Lyons and Quinn (2010) suggests that Psychology grew in popularity in Australia from its introduction in the early 1990s through to the mid-2000s.

Research has explored why there are declining participation rates in the traditional sciences. The reasons students choose or do not choose to continue studying science in senior secondary school are complex and impacted on by a range of factors (Pike and Dunne 2011). There is some evidence that fewer students are choosing science due to competition from subjects that have been introduced as curriculum offerings have broadened (Kennedy et al. 2014; Lyons and Quinn 2010). Many students also perceive science subjects as of limited use and irrelevant to personal career pathways. Biology, Chemistry and Physics are often perceived as elitist and as subjects just taken in pursuit of tertiary education pathways (Goodrum et al. 2012).
particular, students who do take Chemistry and Physics do so because they see a strong connection between these studies and future careers, and because they believe doing so will improve their chances of university entry (Lyons and Quinn 2010). Other reasons cited by students who do not take sciences are that they find them difficult and/or boring (Goodrum et al. 2012) consistent with an international trend of waning student interest in science across many Western nations (van Gijthuijzen et al. 2015). Australian students who do report an interest in science are most likely to attribute this interest to their experiences in early secondary school (Goodrum et al. 2012). In fact, studies show that student attitudes towards science become fixed for most (though not all) students during the early years of secondary school (Archer et al. 2013; Sheldrake et al. 2017; Wang et al. 2017).

SES and Science

A student’s socioeconomic status refers to their family’s social and economic standing and is commonly measured using the income and education levels of the parents (O’Leary 2007). In Australia, SES appears to impact science achievement (Thomson et al. 2017a, b). The TIMSS uses a variety of indicators of SES and all show correlation with science achievement, with students with fewer books, fewer educational resources, and parents with lower levels of education, all performing more poorly in science than their more advantaged counterparts (Thomson et al. 2017b). In the 2015 PISA tests of scientific literacy, the gap between the lowest and highest SES students was 91 points, and the gap between each SES quartile was equivalent to one year of schooling (Thomson et al. 2017a). Unfortunately, Australia is part of an international trend, as SES appears to impact significantly on science achievement (OECD 2018). Across all OECD countries, disadvantaged students scored on average 88 points less than advantaged students in the 2015 PISA tests. However, it is worth noting that the same data shows this disparity is not inevitable, with some high-performing nations showing a far weaker relationship between SES and science achievement.

Not only is there a correlation between SES and science achievement, there seems to be a relationship between SES and student engagement in science. In Australia, Cooper et al. (2018) found that the higher the SES of students 15 years or older, the more likely they would be enrolled in a science subject. An earlier study suggested that high SES students were more likely than others to enrol in Chemistry or Physics (Fullarton et al. 2003). Students from higher SES backgrounds report having higher levels of interest in science and enjoyment in learning science (Thomson et al. 2017a). Lower SES students were less likely to see career and job opportunities as a motivating factor in their science studies (Thomson et al. 2017a). This reflects an international trend where disadvantaged students are less likely to aspire to a career in science, even when accounting for science achievement (OECD 2018).

Location and Science

Whether a school is located in a metropolitan or non-metropolitan area also appears to have significant impact on student achievement and engagement in science education. Metropolitan schools are those that are located in major urban centres, whereas non-metropolitan schools include schools in regional centres, rural towns and remote districts. Both PISA testing and TIMSS testing suggest that Australian students in metropolitan schools significantly outperform students from non-metropolitan schools in science achievement (Thomson et al. 2017a, b), with PISA testing suggesting the divide is the equivalent of at least one year of schooling (Thomson 2017a).
et al. 2017a). National testing of scientific literacy reveals a similar pattern of achievement (Conolly 2017). The 2015 PISA survey of Australian students’ motivations and beliefs in science revealed that metropolitan students were more likely to view science as contributing to their career pathway and job prospects. Furthermore, metropolitan students were more likely to report an interest in science and enjoyment in learning science (Thomson et al. 2017a). In contrast, students attending small rural or remote schools were less likely to enjoy science subjects or to prefer science subjects to other subjects (Lyons and Quinn 2010).

Method

This paper presents analyses of patterns of participation and achievement in science subjects offered within the VCE. The VCE is usually completed over 2 years and is composed of six-month-long units of study, with unit 1 and unit 2 studies benchmarked at a year 11 level and unit 3 and unit 4 studies benchmarked at a year 12 level (Victorian Curriculum and Assessment Authority 2017). Students need to complete 16 units to be awarded the VCE, including three English units and three unit 3–4 sequences in addition to English. However, usually, students complete more units than this, with students typically taking 12 units at year 11 level and 10 units at year 12 level. Year 11 level units are assessed only as satisfactory or unsatisfactory. Students complete a combination of school-based and external assessments in year 12 level units that allow them to earn a study score for the subject. Subject study scores are used to determine a student’s Australian Tertiary Admission Rank (ATAR). Australian tertiary institutions use the ATAR to determine which candidates to offer tertiary education placements to.

There are five science subjects on offer in the VCE: Biology, Chemistry, Environmental Science, Physics and Psychology. Students may elect to take none, one or more of these (Victorian Curriculum and Assessment Authority 2017). Each is offered at both the year 11 and year 12 levels; however, the year 11 units are not prerequisites for the year 12 subjects. While many university courses recommend that students complete a science subject at year 12 level, only Biology, Chemistry and Physics are ever listed explicitly by any Victorian tertiary institution as a prerequisite for entry into any of their courses (Victorian Tertiary Admissions Centre 2016).

Study Data

The data used in this study included information about school location and SES, VCE science enrolment numbers and median study scores in science subjects for each of the 236 schools offering a VCE programme in 2014, 2015 and 2016. This data is routinely collected about every Victorian government secondary school by the Victorian Department of Education and Training (DET). Sampling across three recent years moderates cohort effects while also generating contemporary baseline findings for future comparisons.

Outcome Variables

Schools from different locations and serving communities of different socioeconomic status were compared using three outcome variables: subjects provided, enrolment proportion and achievement level.
The subjects provided variable tracks which of the five science subjects any particular school had students studying at year 11 or year 12 level across the three years (2014, 2015 and 2016).

Enrolment proportions for each science subject were calculated for each school delivering that subject by dividing the number of enrolments in a particular science unit by the total number of VCE enrolments at that particular level and then averaging this result across the three years (2014, 2015 and 2016). As a point of comparison, English, a subject that the vast majority of students enrol in, had an enrolment proportion of 0.157 at year 11 and 0.167 at year 12, meaning that on average, 15.7% and 16.7% of subject enrolments were in this subject at these year levels respectively.

Study scores are only available for the year 12 subjects so achievement levels were calculated only for each year 12 science subject. They were calculated for each school running a particular science in all three years (2014, 2015 and 2016) by averaging the median school year 12 study score for that subject from each of the three years. Study scores are standardised by the VCAA by ranking student performance in each subject and then allocating normalised student study scores according to rank, with a maximum of 50, a set mean of 39 and a standard deviation of 7 (Victorian Curriculum and Assessment Authority 2017). Given this, it is legitimate to compare study scores from school to school and year to year.

Explanatory Variables

Two explanatory variables are considered in this study: Student Family Occupation and Education (SFOE) Index and school location.

The SFOE index of each school is calculated by DET using both parental education levels and occupation categories as recorded in school enrolment details (Department of Education and Training 2016). The higher the SFOE, the lower the SES of the school community, and the greater the disadvantage of families at the school. In some analyses, the SFOE is analysed in quartiles, with the first SFOE quartile including the highest SES schools and the fourth SFOE quartile the lowest SES schools.

To create the school location variable, schools were categorised as either metropolitan (N = 164), if located in a local government area (LGA) within the Greater Melbourne area, or non-metropolitan (N = 122), if located in a LGA in any other region in Victoria (Victorian Government 2017). Consequently, schools classified as non-metropolitan include schools in regional cities as well as in rural and remote locations.

Analysis

As this study used data from the entire population of interest, sampling error was not a risk and therefore calculations of statistical significance were not required. The focus was on the practical significance of the statistics only (Cohen et al. 2011).

Descriptive statistics were used to summarise patterns of participation and achievement in science subjects across location and SES categories. The proportions of schools providing the different science subjects, and the means and ranges of enrolment proportions, and the achievement levels in the year 12 subjects, were compared by school location and SFOE quartile. The relationships between both enrolment proportions, achievement level, and SFOE were further investigated using Spearman’s rho correlation coefficients. Coefficients were calculated for all schools, for metropolitan schools and for non-metropolitan schools respectively to identify possible interaction effects between SES and location. The strength of
correlation coefficients were interpreted using Cohen’s (1988) guidelines: small = 0.10; medium = 0.30; large = 0.50.

Results

VCE Science Subjects Provided

The proportion of schools offering each of the VCE sciences in metropolitan and non-metropolitan schools was calculated for each year of the study (2014, 2015 and 2016). Table 1 shows the lowest and highest proportions of metropolitan and non-metropolitan schools, respectively, offering each science subject during the study period. It shows that Environmental Science is only offered by a small proportion of schools across the state. The other four subjects are all widely available in metropolitan schools, with only a few schools out of every hundred not providing any one of these studies in any one year. These subjects are not as widely available in non-metropolitan locations, with each, other than year 11 Biology, not provided in 10% or more non-metropolitan schools at some point between 2014 and 2016.

Table 2 shows the lowest and highest proportions of schools offering each of the VCE sciences during the study period in schools in each of the SES quartiles. It shows that the lowest SES schools were generally less likely to provide each of the science subjects than the highest SES school, with the exception of year 11 and 12 Psychology. This difference was most prominent for Chemistry and Physics. Schools in the second SFOE quartile were most likely to be providing year 11 and 12 Environmental Science.

Enrolment Proportions

Table 3 lists the mean enrolment proportions and the range of enrolment proportions for each of the VCE studies by location. It reveals that Psychology is the most popular of the sciences, followed by Biology, whereas Chemistry and Physics, the enabling sciences, as well as Environmental Science, attract far fewer enrolments. Further, Biology, Environmental Science and Psychology attract higher enrolment proportions in year 12 than in year 11, suggesting these subjects draw in additional students for study at the year 12 level. In contrast, Chemistry seems to suffer some attrition between years 11 and 12, while Physics enrolments stay steady.

Table 1 Variance in the proportion of schools providing VCE science subjects during the study period, by location

<table>
<thead>
<tr>
<th></th>
<th>Metropolitan schools (N=164) (%)</th>
<th>Non-metropolitan schools (N=122) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 Biology</td>
<td>96-99</td>
<td>94-98</td>
</tr>
<tr>
<td>Year 12 Biology</td>
<td>95-97</td>
<td>87-94</td>
</tr>
<tr>
<td>Year 11 Chemistry</td>
<td>96-98</td>
<td>88-93</td>
</tr>
<tr>
<td>Year 12 Chemistry</td>
<td>95-96</td>
<td>87-91</td>
</tr>
<tr>
<td>Year 11 Environmental Science</td>
<td>6-11</td>
<td>2-7</td>
</tr>
<tr>
<td>Year 12 Environmental Science</td>
<td>7-8</td>
<td>3-11</td>
</tr>
<tr>
<td>Year 11 Physics</td>
<td>95-97</td>
<td>89-92</td>
</tr>
<tr>
<td>Year 12 Physics</td>
<td>92-95</td>
<td>82-88</td>
</tr>
<tr>
<td>Year 11 Psychology</td>
<td>98-99</td>
<td>84-91</td>
</tr>
<tr>
<td>Year 12 Psychology</td>
<td>97-98</td>
<td>89-90</td>
</tr>
</tbody>
</table>
Table 2  Variance in the proportion of schools providing VCE science subjects during the study period, by SFOE quartile

<table>
<thead>
<tr>
<th></th>
<th>1st quartile SFOE schools (highest SES) (N = 72) (%)</th>
<th>2nd quartile SFOE schools (N = 71) (%)</th>
<th>3rd quartile SFOE schools (N = 72) (%)</th>
<th>4th quartile SFOE schools (lowest SES) (N = 71) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 Biology</td>
<td>97-99</td>
<td>94-99</td>
<td>92-97</td>
<td>93-97</td>
</tr>
<tr>
<td>Year 12 Biology</td>
<td>94-99</td>
<td>93-96</td>
<td>90-96</td>
<td>90-96</td>
</tr>
<tr>
<td>Year 11 Chemistry</td>
<td>96-99</td>
<td>93-94</td>
<td>92-93</td>
<td>90-94</td>
</tr>
<tr>
<td>Year 12 Chemistry</td>
<td>96-97</td>
<td>92-94</td>
<td>86-94</td>
<td>89-92</td>
</tr>
<tr>
<td>Year 11 Environmental Science</td>
<td>8–11</td>
<td>7–15</td>
<td>3–6</td>
<td>3-4</td>
</tr>
<tr>
<td>Year 12 Environmental Science</td>
<td>6–7</td>
<td>8–17</td>
<td>3–8</td>
<td>4–6</td>
</tr>
<tr>
<td>Year 11 Physics</td>
<td>97–100</td>
<td>90-93</td>
<td>88-94</td>
<td>89-93</td>
</tr>
<tr>
<td>Year 12 Physics</td>
<td>93-97</td>
<td>86-94</td>
<td>86-90</td>
<td>83-86</td>
</tr>
<tr>
<td>Year 11 Psychology</td>
<td>94-100</td>
<td>89-93</td>
<td>86-96</td>
<td>97-99</td>
</tr>
<tr>
<td>Year 12 Psychology</td>
<td>93-100</td>
<td>90-93</td>
<td>90-96</td>
<td>96-99</td>
</tr>
</tbody>
</table>

These data also suggest that the enrolment proportions of some sciences vary to some degree with location. Chemistry attracts slightly more enrolments in metropolitan schools than in non-metropolitan schools, while the reverse is true for Biology and Environmental Science.

Table 4 lists the mean enrolment proportions and the range of enrolment proportions for each of the VCE studies by SFOE quartile. It illustrates some differences in the enrolment proportions of some subjects in schools of different SES. Chemistry and Physics both attract a greater share of enrolments in the highest SES schools than in schools at other SES levels. In contrast, year 12 Psychology attracts greater enrolment proportions in the lowest SES schools than in any other SES level. Curiously, schools in the second highest SES quartile attracted far higher enrolment proportions in Environmental Science than schools from other SES categories.

Spearman’s rho correlation coefficients were calculated to explore the relationship between SFOE and enrolment proportions further. Table 5 lists the correlation coefficients for each subject, across all schools, metropolitan schools and non-metropolitan schools. The data in Table 5 shows that there is no linear relationship between SFOE and the enrolment proportions.
### Table 4: Enrolments in VCE science subjects as a proportion of all VCE subject enrolments by school location and SOFO quartile

<table>
<thead>
<tr>
<th>Subject</th>
<th>1st quartile SOFO schools (highest SES) (N=77) Mean (range)</th>
<th>2nd quartile SOFO schools (N=71) Mean (range)</th>
<th>3rd quartile SOFO schools (N=73) Mean (range)</th>
<th>4th quartile SOFO schools (lowest SES) (N=71) Mean (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 Biology</td>
<td>0.049 (0.019-0.089)</td>
<td>0.654 (0.007-0.136)</td>
<td>0.048 (0.003-0.084)</td>
<td>0.048 (0.004-0.089)</td>
</tr>
<tr>
<td>Year 12 Biology</td>
<td>0.050 (0.015-0.103)</td>
<td>0.657 (0.027-0.163)</td>
<td>0.052 (0.022-0.130)</td>
<td>0.049 (0.017-0.082)</td>
</tr>
<tr>
<td>Year 11 Chemistry</td>
<td>0.048 (0.011-0.167)</td>
<td>0.634 (0.013-0.064)</td>
<td>0.031 (0.002-0.065)</td>
<td>0.031 (0.002-0.074)</td>
</tr>
<tr>
<td>Year 12 Chemistry</td>
<td>0.040 (0.008-0.161)</td>
<td>0.629 (0.011-0.098)</td>
<td>0.026 (0.005-0.053)</td>
<td>0.027 (0.004-0.061)</td>
</tr>
<tr>
<td>Year 11 Environmental Science</td>
<td>0.066 (0.003-0.011)</td>
<td>0.614 (0.002-0.050)</td>
<td>0.095 (0.006-0.112)</td>
<td>0.095 (0.001-0.111)</td>
</tr>
<tr>
<td>Year 12 Environmental Science</td>
<td>0.070 (0.002-0.026)</td>
<td>0.621 (0.008-0.098)</td>
<td>0.055 (0.004-0.121)</td>
<td>0.013 (0.008-0.022)</td>
</tr>
<tr>
<td>Year 11 Physics</td>
<td>0.014 (0.008-0.074)</td>
<td>0.626 (0.006-0.063)</td>
<td>0.025 (0.002-0.073)</td>
<td>0.022 (0.001-0.059)</td>
</tr>
<tr>
<td>Year 12 Physics</td>
<td>0.022 (0.006-0.078)</td>
<td>0.624 (0.005-0.059)</td>
<td>0.025 (0.005-0.083)</td>
<td>0.022 (0.003-0.049)</td>
</tr>
<tr>
<td>Year 11 Psychology</td>
<td>0.057 (0.016-0.119)</td>
<td>0.658 (0.015-0.138)</td>
<td>0.057 (0.032-0.105)</td>
<td>0.059 (0.028-0.135)</td>
</tr>
<tr>
<td>Year 12 Psychology</td>
<td>0.064 (0.008-0.113)</td>
<td>0.660 (0.012-0.192)</td>
<td>0.068 (0.024-0.124)</td>
<td>0.074 (0.005-0.163)</td>
</tr>
</tbody>
</table>
Table 5  Spearman’s rho correlation coefficients for SFOE and VCE science subject enrolment proportions by all schools, metropolitan schools and non-metropolitan schools

<table>
<thead>
<tr>
<th></th>
<th>All schools Rho (N)</th>
<th>Metropolitan schools Rho (N)</th>
<th>Non-metropolitan schools Rho (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11 Biology</td>
<td>-0.08 (285)</td>
<td>-0.10 (164)</td>
<td>-0.11 (121)</td>
</tr>
<tr>
<td>Year 12 Biology</td>
<td>-0.03 (282)</td>
<td>-0.07 (169)</td>
<td>-0.05 (122)</td>
</tr>
<tr>
<td>Year 11 Chemistry</td>
<td>-0.30 (279)</td>
<td>-0.32 (162)</td>
<td>-0.29 (177)</td>
</tr>
<tr>
<td>Year 12 Chemistry</td>
<td>-0.21 (276)</td>
<td>-0.23 (159)</td>
<td>-0.22 (117)</td>
</tr>
<tr>
<td>Year 11 Environmental Science</td>
<td>-0.10 (38)</td>
<td>-0.23 (27)</td>
<td>0.12 (11)</td>
</tr>
<tr>
<td>Year 12 Environmental Science</td>
<td>-0.16 (41)</td>
<td>-0.34 (23)</td>
<td>0.03 (13)</td>
</tr>
<tr>
<td>Year 11 Physics</td>
<td>-0.32 (281)</td>
<td>-0.33 (161)</td>
<td>-0.29 (120)</td>
</tr>
<tr>
<td>Year 12 Physics</td>
<td>-0.25 (278)</td>
<td>-0.25 (166)</td>
<td>-0.24 (118)</td>
</tr>
<tr>
<td>Year 11 Psychology</td>
<td>-0.01 (284)</td>
<td>0.04 (164)</td>
<td>-0.03 (120)</td>
</tr>
<tr>
<td>Year 12 Psychology</td>
<td>0.15 (285)</td>
<td>0.13 (164)</td>
<td>0.23 (121)</td>
</tr>
</tbody>
</table>

of year 11 Biology, year 12 Biology, or year 11 Psychology, and small to small-medium negative correlations in all the other sciences, independent of location. This suggests that school SFOE is not a strong predictor of enrolment proportions in any of the STEM subjects.

Achievement Level

Table 6 lists the mean study score and range of study scores for each science subject, achieved in all schools, metropolitan schools and non-metropolitan schools. It shows that on average, students in metropolitan schools achieve higher study scores in all the sciences than students in non-metropolitan schools. However, the margins are all less than 1 study score point, being 0.79, 0.00, 0.36, 0.54 and 0.93 for Biology, Chemistry, Environmental Science, Physics and Psychology respectively. Further, the achievement range of non-metropolitan schools is similar to the range of metropolitan schools for each of the sciences, except Biology.

Table 7 lists the mean study score and range of study scores for each science subject, by SES quartile. It shows that achievement levels in the sciences vary considerably with SES. In Biology, Chemistry, Environmental Science, Physics and Psychology, the highest SES school’s average study scores are 5.03, 4.63, 8.85, 4.01 and 4.85 points higher than those of the lowest SES schools in these subjects respectively.

Spearman’s rho correlation coefficients were also calculated to explore the relationship between SFOE and achievement levels. Table 8 lists the correlation coefficients for each subject, across all schools, metropolitan schools and non-metropolitan schools respectively. As can be seen in Table 8, there is a large negative correlation between SFOE and achievement

Table 6  Comparison of schools’ achievement levels in VCE year 12 science subjects, where results were available for 2014, 2015 and 2016, by location

<table>
<thead>
<tr>
<th>Subject</th>
<th>All schools</th>
<th>Metropolitan schools</th>
<th>Non-metropolitan schools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (range)</td>
<td>N</td>
</tr>
<tr>
<td>Biology</td>
<td>282</td>
<td>27.16 (16.00 - 41.31)</td>
<td>160</td>
</tr>
<tr>
<td>Chemistry</td>
<td>276</td>
<td>26.43 (15.00 - 35.69)</td>
<td>159</td>
</tr>
<tr>
<td>Environmental Science</td>
<td>37</td>
<td>28.39 (19.36 - 40.08)</td>
<td>20</td>
</tr>
<tr>
<td>Physics</td>
<td>278</td>
<td>27.20 (11.67 - 37.53)</td>
<td>160</td>
</tr>
<tr>
<td>Psychology</td>
<td>264</td>
<td>27.82 (15.22 - 36.92)</td>
<td>163</td>
</tr>
</tbody>
</table>
Table 7: Comparison of schools’ achievement levels in VCE year 12 science subjects, where results were available for 2014, 2015 and 2016, by SFOE quartile

<table>
<thead>
<tr>
<th>Subject</th>
<th>1st quartile SFOE schools (highest SES)</th>
<th>2nd quartile SFOE schools</th>
<th>3rd quartile SFOE schools</th>
<th>4th quartile SFOE schools (lowest SES)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (range)</td>
<td>N</td>
<td>Mean (range)</td>
</tr>
<tr>
<td>Biology</td>
<td>72</td>
<td>29.92 (22.83–41.31)</td>
<td>70</td>
<td>27.65 (23.00–33.08)</td>
</tr>
<tr>
<td>Chemistry</td>
<td>71</td>
<td>29.14 (18.88–35.69)</td>
<td>69</td>
<td>26.86 (19.33–34.00)</td>
</tr>
<tr>
<td>Environmental Science</td>
<td>8</td>
<td>31.73 (27.00–40.89)</td>
<td>19</td>
<td>28.78 (21.50–43.00)</td>
</tr>
<tr>
<td>Physics</td>
<td>72</td>
<td>29.44 (20.73–37.53)</td>
<td>69</td>
<td>27.46 (11.67–37.00)</td>
</tr>
<tr>
<td>Psychology</td>
<td>72</td>
<td>30.48 (23.85–39.92)</td>
<td>70</td>
<td>28.30 (21.79–36.00)</td>
</tr>
</tbody>
</table>
Table 8  Spearman’s rho correlation coefficients for SFOE and VCE year 12 science subject achievement levels for all schools, metropolitan schools and non-metropolitan schools

<table>
<thead>
<tr>
<th>Subject</th>
<th>All schools Rho (N)</th>
<th>Metropolitan schools Rho (N)</th>
<th>Non-metropolitan schools Rho (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td>-0.56 (282)</td>
<td>-0.66 (166)</td>
<td>-0.39 (122)</td>
</tr>
<tr>
<td>Chemistry</td>
<td>-0.51 (276)</td>
<td>-0.66 (159)</td>
<td>-0.23 (117)</td>
</tr>
<tr>
<td>Environmental Science</td>
<td>-0.56 (37)</td>
<td>-0.67 (20)</td>
<td>-0.20 (17)</td>
</tr>
<tr>
<td>Physics</td>
<td>-0.45 (278)</td>
<td>-0.61 (166)</td>
<td>-0.15 (118)</td>
</tr>
<tr>
<td>Psychology</td>
<td>-0.59 (294)</td>
<td>-0.69 (163)</td>
<td>-0.38 (121)</td>
</tr>
</tbody>
</table>

across all schools in all of the science subjects, except for Physics where there is a medium to large correlation. These correlations strengthen when only metropolitan schools are included in the calculation. Conversely, the correlations weaken when only non-metropolitan schools are considered, becoming medium strength for Chemistry and Psychology, and small for all other sciences. This suggests that SFOE is a strong predictor of achievement in all sciences in metropolitan schools, but a far weaker predictor of achievement in non-metropolitan schools.

Discussion and Implications

This study set out to explore the impact of school SES and school location on participation and achievement in VCE science subjects in all Australian Victorian government secondary schools. To do this, it used de-identified data from all Victorian government secondary schools offering a VCE science subject across the three years of 2014, 2015 and 2016. Three outcome variables were examined: the VCE science subjects provided by each school, each school’s proportional enrolments in each science subject (as a proportion of all VCE subject enrolments), and the average achievement levels of students completing VCE science subjects at year 12 level in each school. While the analysis revealed significant new knowledge about the patterns of participation and achievement, the data is unable to reveal why these relationships exist. Further, the data used does not account for the impact of student characteristics, such as indigeneity, ethnicity or gender, on the relationships observed in this study, though research suggests these characteristics do impact on participation and achievement in science (Connolly 2017; Thomson et al. 2017a).

This study confirms the findings of previous research that students attending lower SES schools are less likely to study or achieve well in VCE science (Thomson et al. 2017a, b), but reveals that provision and participation rates vary by science subject. Biology and Psychology are provided by most schools, no matter the SES; however, there is a sizable gap in the provision of Chemistry and Physics between the highest and the lowest SES schools. Where schools were able to provide these subjects, this study shows that enrolment proportions vary little in Biology and Psychology across the SES quartiles. There is also very little variation in the enrolment proportions in Chemistry or Physics across the three lower SES quartiles; however, students from the highest SES schools enrolled in far higher proportions in these subjects. This pattern appears not to have changed since it was observed by Fullarton et al. (2003). In line with research showing a positive correlation between SES and science performance (for example, Thomson et al. 2017a), this study showed a strong relationship...
between SES and study scores in all five of the VCE sciences. Students from the highest SES schools outperformed students from the lowest SES schools by at least 4 study score points.

The study shows some interesting patterns of participation and achievement when comparing metropolitan and non-metropolitan schools. On average, non-metropolitan schools were less likely than metropolitan schools to provide all five of the VCE sciences, with the difference being most marked in rates of offering year 12 physics. This is possibly unsurprising, given the difficulties rural schools have recruiting science teachers (Lyon et al. 2006; Marginson et al. 2013). However, where non-metropolitan schools were able to offer the VCE sciences, the uptake of these subjects was quite similar to the uptake in metropolitan schools, seemingly challenging the findings of research that suggest non-metropolitan students are less likely to engage with the sciences (Lyons and Quinn 2010; Thomson et al. 2017a). Further, while this study’s findings confirm that metropolitan students tend to outperform non-metropolitan students in science, the study reveals only a small gap in performance, with non-metropolitan students average study scores being within 1 point of their metropolitan counterparts for all of the sciences. Promisingly, the range of mean science study scores for non-metropolitan schools is similar to the range found in metropolitan schools, suggesting that some non-metropolitan schools have students achieving very well in the sciences despite their location.

Most revealing is that these findings suggest an interaction effect between location and SES. From the results, it appears that a non-metropolitan school location moderates the impact of SES on achievement in science. In metropolitan schools, there is a strong correlation between SES and achievement in each of the VCE sciences. However, in non-metropolitan schools, this correlation is weak to negligible. This suggests that a non-metropolitan location is somehow protective against the impact of SES on achievement in science. The literature provides few clues as to why this may be the case. There is some research suggesting that successful rural schools build strong links with both school families and the wider community (Barley and Boesley 2007; Hardre 2011; Semke and Sheridan 2012). It is reasonable to speculate that rural schools may make use of these ties to use the local natural environment, industry and agriculture to enhance engagement and learning in the sciences.

The reasons behind the strong performance of some non-metropolitan schools, and the apparent protective effect a non-metropolitan location has on the impact of SES on science achievement warrant further exploration. These findings echo those found in the sister study to this one focussed upon senior Mathematics (Murphy 2018). Together, the findings of these studies suggest research into aspects of rural education that can support improved performance in science and mathematics would be a valuable line of inquiry. Data similar to that used in these studies could be used to identify Victorian sites worthy of case study to investigate the education practices that have led to these schools relative success. It is important to note that this study used data only from Victorian schools. Further investigation is required to see if these results are found in other jurisdictions.

A significant equity concern is that this study shows that students from low SES schools or non-metropolitan schools are less likely to study, or achieve well in, chemistry or physics. These subjects are listed as prerequisites for access to a wide range of tertiary pathways to science and science-related careers, particularly in engineering (Victoria Tertiary Admissions Centre 2016). Low SES and non-metropolitan students’ low participation and achievement in these subjects mean that they will have limited access to industries with a growing demand for workers (Australian Industry Group 2015), potentially perpetuating their disadvantage. Given that biology and psychology enrolment proportions do not vary in the same way with SES or
location, it may be worth investigating the reasons students enrol in the different sciences to look for clues to redress the inequity in enrolment rates in chemistry and physics.

These findings warrant the attention of policy makers and educators. They highlight inequities in science education in senior secondary school that require context specific action to be taken. While both low SES and non-metropolitan students tend to achieve less well in all sciences, and enrol in lower proportions in chemistry and physics, this study suggests that the actions required to redress these problems may not be the same. Non-metropolitan location seems to mitigate against the impact of SES on science achievement, suggesting that this context is quite different to a metropolitan context. Given this, interventions to improve achievement in lower SES schools in metropolitan schools will, in all likelihood, need to be different to interventions in non-metropolitan schools.

This study has several limitations. Firstly, the analysis does not include data drawn from independent or Catholic schools. Further investigation would be required to determine if SES and location have similar impacts on science participation and achievement in the non-government education sector. It might be speculated that not including this data set could impact the variation in performance and engagement observed in this study. It is reasonable to assume that non-metropolitan government schools are less likely to have direct competition for students from independent schools than metropolitan schools, due to their more remote location. Given this, non-metropolitan schools may be more likely to retain potentially higher achieving high SES students, raising the average achievement of these schools. However, following this logic, the retention of those students in non-metropolitan schools would also raise the school SES, thus preserving the relationships observed in this study.

In addition, while this study reveals relationships between school SES and location and science participation and achievement, the data analysed in this study do not explain why these relationships exist. This study also does not reveal anything of the role that student characteristics, such as gender, indigeneity and ethnicity, may have in moderating the relationships observed, yet these variables are likely to inter-relate with the variables discussed in this paper (Thomson et al. 2017a).

Conclusion

This study confirms that the positive correlation previously observed between SES and achievement in science in junior secondary school also exists in the final year of secondary school. Students in high SES schools are also more likely to study senior Chemistry and Physics; however, this pattern is not true for Biology, Environmental Science or Psychology. Aligning with previous research, metropolitan students achieve better results than their non-metropolitan counterparts; however, the differences found in this study are relatively small for all the science subjects. Contrary to the suggestions of other studies, these findings show that non-metropolitan students enrol in senior sciences at a similar rate to metropolitan students. The study also suggests an interaction effect between location and SES not noted in the current literature, where science achievement in non-metropolitan schools appears less impacted upon by SES than that in similar metropolitan schools. Further research is needed to explore how a non-metropolitan location may be protective against the impact of SES on achievement in science.

Acknowledgements. The author would like to acknowledge the support of his supervisory team, Dr Lena Danaia, Dr Amy MacDonald and Dr Audrey Wang.
References


Participation and achievement in technology education: the impact of school location and socioeconomic status on senior secondary technology studies

Steve Murphy

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Abstract
The rise of STEM education, and the twenty first century skills movement, and the increasingly technologically driven nature of our world, has pushed technology education to the fore in recent times. Technology education faces a range of equity issues and there has been a particular focus on gender issues. This study considers two less explored equity issues: school location and socioeconomic status (SES). Using data routinely collected in Victoria, Australia by the Department of Education and Training, senior school technology subject provision, enrolment and achievement patterns were examined by location and SES. Though little difference was found in the academic performance of students from metropolitan or non-metropolitan locations in technology subjects, there were notable differences in participation. Non-metropolitan students were more likely to enrol in design technology and engineering subjects than students attending metropolitan schools. However, while nonmetropolitan student’s enrolled in the digital technology subjects at a similar rate to metropolitan students, nonmetropolitan students were less likely to have access to these subjects. Students from lower SES schools tended to perform more poorly in technology subjects than students from high SES backgrounds. Further, the lowest SES schools were the least likely to offer technology subjects. This skewed access to, and performance in, technology subjects by SES and location, highlights significant equity issues in technology education that have attracted only limited attention in the literature.

Keywords Design technology · Digital technology · Equity · Socioeconomic status · Rural · Metropolitan

Introduction
Internationally, there is an emerging consensus around the importance of technology capabilities and technology education. The rise of the Science, Technology, Engineering and Mathematics (STEM) education movement over the past 20 years, particularly in western
education systems, has placed technology and engineering education firmly on the agenda in many countries (Blackley and Howell 2015). The ubiquitous nature of computing has provided significant impetus for education in digital technologies (Webb et al. 2017). The identification of creativity, critical thinking and problem solving as key skills for the twenty first century (Partnership for 21st Century Learning 2007) provides strong justification for students to become adept in design and engineering thinking. Finally, calls from industry to build students’ skills in technology and engineering highlights the importance of technology education (Australian Industry Group [AIG] 2013; Morgan and Kirby 2016).

There is strong emphasis on technology education in Australia. Industry and advisory groups advocate for improvements in STEM education to supply industry with a technically skilled workforce (AIG 2015; Office of the Chief Scientist 2014). The Australian National Education Council and most of the Australian jurisdictions have released STEM education strategies aimed at building student capabilities in the STEM disciplines as well as in interdisciplinary skills such as problem solving and ICT skills (Murphy et al. 2018). These same strategies emphasise the need for authentic learning opportunities where students produce solutions to real world problems, effectively placing emphasis on the pedagogical contribution of technology education to STEM education.

Many of the Australian STEM education strategies also flag equity issues that need to be addressed in STEM education, amongst them issues associated with school socioeconomic status (SES) and with school remoteness. The current study is part of a wider program of research exploring the impact of these two factors on student engagement and performance in each of the STEM disciplines. This paper explores the relationship of SES and location with secondary school provision, enrolment and achievement in the senior technology subjects. It asks two research questions:

1. What is the relationship between school SES (the aggregate socioeconomic status of students at the school) and provision, enrolment and achievement in the Victorian Certificate of Education (VCE) technology subjects?
2. What is the relationship between the location of a school (metropolitan or non-metropolitan) and provision, enrolment and achievement in the VCE technology subjects?

There are a wide range of technology subjects that can be offered as part of the VCE and can be classified as either ‘digital technology’, ‘design technology’ or ‘engineering’ (Kennedy et al. 2018). Those included in this study are shown in Table 1.

The VCE includes an array of potential pathways in digital technology. Computing focuses on problem solving when working with information systems and digital tools (Victorian Curriculum and Assessment Authority [VCAA] 2016). At Unit 1 and 2 Computing (known as Information Technology prior to 2016) retains a broad focus, however students can choose to focus either on data management and the use of information systems in Informatics Units 3 and 4, or creating digital solutions to problems through programming in Software development Units 3 and 4. A further digital technology subject, Algorithmics, was introduced in 2015 (VCAA 2018). It examines the use of algorithms as a tool to solve real world problems, as a foundation for computer science and software engineering.

The VCE offers three subjects classified as design technology. Product Design and Technology has students exercising design thinking processes and using a range of tools and materials to produce physical, functional products (VCAA 2011). Food and technology develops students’ understanding of the design process as it relates to the development of food products (VCAA 2014). Agricultural and horticultural studies is classified as a design
Table 1  Classification of VCE Technology subjects as Digital technology, Design technology or Engineering

<table>
<thead>
<tr>
<th>Subject classification</th>
<th>VCE technology subject</th>
</tr>
</thead>
</table>
| Digital technology (focus on computer use and programming) | Computing (previously Information technology)—Units 1 and 2  
  Computing: Informatics (previously IT applications)—Units 3 and 4  
  Computing: Software development—Units 3 and 4  
  Algorithmics—Units 3 and 4 |
| Design technology (focus on design and use of technology) | Product design and technology—Units 1–4  
  Food and technology—Units 1–4  
  Agricultural and horticultural studies—Units 1–4 |
| Engineering (focus on engineering thinking) | Systems engineering—Units 1–4 |


technology subject given its focus on problem solving to produce food and fibre (VCAA 2010).

Finally, the VCE includes one engineering subject, Systems engineering. This subject encourages students to develop design and problem solving skills as they relate to integrated systems, such as energy, water or land management, transportation, automation or robotics (VCAA 2012).

**Literature**

This study posits that a school successful in technology education has a relatively high proportion of students enrolling in senior technology subjects, and that these students attain relatively high academic results in these subjects. It then examines the impact of two school level contextual factors that research suggests impacts student enrolment and achievement in STEM disciplines, school SES and school location (Australian Curriculum Assessment and Reporting Authority [ACARA] 2014; Elsworth et al. 1999; Murphy 2018a, b).

**Equity and technology education**

Gender appears to be the most prominent equity issue explored in technology education research. Internationally, lobby groups promote gender as a prime concern given the under-representation of females in technology based careers (e.g. AIG 2013; Morgan and Kirby 2016; UNESCO 2017). Studies point to significant gender imbalance in enrolments in senior secondary technology subjects (Elsworth et al. 1999; Kennedy et al. 2018) and tertiary education participation in related studies such as engineering and computer science (Michell et al. 2017). Secondary school technology education is seen as masculine in nature (Dukers et al. 2009) and significant effort has been invested in exploring ways to redress this concern (e.g. Caleb 2000; Fields et al. 2018; Hur et al. 2017). However, there

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are other equity issues impacting on student participation and success in both digital and design technology subjects.

**SES and technology subjects**

In the literature, participation in secondary school technology subjects appears to be associated with coming from a lower SES background. A United Kingdom study suggested that working class students take subjects like home economics and business studies in preferences to languages or history (Davies et al. 2008) and that the SES of the student body influenced the subjects a school offered. Elsworth et al. (1999) found that in Australia lower SES students were more likely to enrol in computing, home science and technology than their higher SES counterparts. The same study also suggested that a lower average school community SES was also associated with students choosing computing and home science. Dar and Geta (2007) found similar patterns in the choice of tertiary degrees by Israeli students, with lower SES students choosing more practical fields such as engineering and computer science, while higher SES students chose more prestigious courses like medicine and law. In Turkey, Hasifazlioglu (2008) found that students from lower income backgrounds were more likely to pursue engineering, where those from higher income families tended to choose the arts and social sciences. Similarly, in a study in the United States, Mullis et al. (1998) showed that students whose parents had unskilled occupations where more likely to be interested in practical and technical careers than those whose parents worked in skilled professions.

Though low SES appears to be associated with participation in technology subjects, it does not appear to be associated with high achievement in these subjects. The United States’ Technology and Engineering Literacy (TEL) assessment of 2014 reported average student performance correlated positively with parental education level and negatively with student eligibility for the national school lunch program (National Assessment of Educational Progress [NAEP] 2014). Ritzhaupt et al. (2013) also found that US students from high SES backgrounds had stronger ICT literacy skills than those from low SES backgrounds. Australia’s National Assessment Program revealed that SES and ICT literacy were positively correlated for Australian Year 6 and 10 students, with parental occupation and education levels both impacting strongly on students’ average results (ACARA 2014).

**Location and technology subjects**

Location has been found to have a significant impact on engagement and achievement in science and mathematics (Murphy 2018a, b; Thomson et al. 2017a, b), but its impact on school technology subjects is less well researched. This author was unable to find studies exploring variation in student participation in technology subjects by location, though there are studies looking at differences in attitudes to ICT for teaching and learning by location (e.g. Kornros 2018; Mehbob U1 and Akbar 2016). There were, however, some studies exploring variation in student achievement in technology by location. In the USA, the Technology and Engineering Literacy (TEL) assessment showed students from cities scored more poorly than other students in technology and engineering literacy, compared to suburban, town or rurally located students (NAEP 2014). However, in Australia, students from metropolitan schools significantly outperformed students from provincial areas, who in turn out performed students from remote schools, in ICT literacy (ACARA 2014).
Method

This study utilised data collected annually by the Victorian Department of Education and Training. It drew data from all 286 Victorian government schools delivering a VCE program from 2014 to 2016. The data used included information about school location and SES, as well as VCE technology subject enrolment numbers and median study scores.

Outcome variables

Schools from different locations and serving communities of different socio-economic status were compared using three outcome variables: Subjects provided, Enrolment proportion, and Achievement level.

The Subjects provided variable tracks which of the technology subjects any particular school had students studying across the 3 years (2014, 2015 and 2016).

Enrolment proportions for each technology subject were determined for each school providing that subject. They were calculated by dividing the number of enrolments in a particular technology subject in a particular school by the total number of VCE enrolments at that particular level in the school and then averaging this result across the 3 years (2014, 2015 and 2016) and reporting the result as a percentage. As a point of comparison, English, a subject that the vast majority of students enrol in, had an enrolment proportion of 15.7% at Year 11 and 16.7% at Year 12.

Study scores are only available for the Year 12 subjects so Achievement levels were calculated only for each Year 12 technology subject. They were calculated by averaging the median school Year 12 study score for a subject from each of 2014, 2015 and 2016 (with the exception of Algorithmics which was first offered in 2015) for each school running that particular technology subject. Each year students are ranked by their performance in each subject by the VCAA. Students are then allocated a normalised study score according to this rank, with a maximum of 30, a set mean of 30 and standard deviation of 7 (VCAA 2017). As the study scores are standardised in this way, it is legitimate to compare study scores from school to school and year to year.

Explanatory variables

Two explanatory variables are considered in this study: Socioeconomic status and School Location.

This paper adopts the Department of Education and Training’s (DET) School Family Occupation and Employment (SFOE) index to produce a measure of SES. The SFOE index is a measure of disadvantage. A score between 0 and 1 is calculated by DET using both parental education levels and occupation categories as recorded in school enrolment data (Department of Education and Training [DET] 2016). The lower the score, the higher the SES of the school community. To convert this to a measure of socioeconomic advantage the SFOE index has been subtracted from 1, producing a measure of SES with a minimum score of 0 and a maximum score of 1, and where the higher the score the higher the SES of the school community.

To create the School Location variable, schools were categorised as either metropolitan (N=164), if located in a local government area (LGA) within the Greater Melbourne area,
or non-metropolitan (N = 122), if located in a LGA in any other region in Victoria (Victorian Government 2017). Consequently, schools classified as non-metropolitan include schools in regional cities as well as rural and remote locations.

**Analysis**

The focus of this analysis was only on the practical significance of the statistics. Calculations of statistical significance were not required as this study used data from the entire population of interest (Cohen et al. 2011).

The proportions of schools providing the different technology subjects, and the means and ranges of enrolment proportions, and the achievement levels in the Year 12 subjects, were compared by school location and SES quartile. The relationships between achievement level and SES were further investigated using Spearman’s rho correlation coefficients. Coefficients were calculated for all schools, for metropolitan schools and for non-metropolitan schools respectively to examine differences in these relationships based on location. The strength of correlation coefficients were interpreted using Cohen’s (1988) guidelines: small = 0.10; medium = 0.30; large = 0.50.

**Results**

**VCE technology subjects and location**

Table 2 shows that Food technology is provided by more schools than any of the other technology subject, with large proportions of schools also providing Year 11 Information

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Variance in the proportion of schools providing VCE technology subjects during the study period by location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metropolitan schools (N = 154) (%)</td>
</tr>
<tr>
<td><strong>Digital technology subjects</strong></td>
<td></td>
</tr>
<tr>
<td>Year 12 Algorithms (HESS)</td>
<td>4-5</td>
</tr>
<tr>
<td>Year 11 Information Technology</td>
<td>65-73</td>
</tr>
<tr>
<td>Year 12 Computing: Informatics</td>
<td>49-52</td>
</tr>
<tr>
<td>Year 12 Computing: Software Development</td>
<td>28-35</td>
</tr>
<tr>
<td><strong>Design technology subjects</strong></td>
<td></td>
</tr>
<tr>
<td>Year 11 Agricultural and Horticultural Studies</td>
<td>1-2</td>
</tr>
<tr>
<td>Year 12 Agricultural and Horticultural Studies</td>
<td>1-2</td>
</tr>
<tr>
<td>Year 11 Food and Technology</td>
<td>70-76</td>
</tr>
<tr>
<td>Year 12 Food and Technology</td>
<td>64-76</td>
</tr>
<tr>
<td>Year 11 Product Design and Technology</td>
<td>49-60</td>
</tr>
<tr>
<td>Year 12 Product Design and Technology</td>
<td>49-52</td>
</tr>
<tr>
<td><strong>Engineering subjects</strong></td>
<td></td>
</tr>
<tr>
<td>Year 11 Systems Engineering</td>
<td>22-25</td>
</tr>
<tr>
<td>Year 12 Systems Engineering</td>
<td>18-21</td>
</tr>
</tbody>
</table>

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technology, and Year 11 Product Design and Technology. Year 12 Algorithmics, introduced in 2015, was only offered by a very small number of schools. Only a small proportion of schools offered Agricultural and Horticultural Studies, or Systems Engineering.

This table also reveals that the provision of technology subjects varies significantly by location. Metropolitan schools were substantially more likely to provide each of the digital technology subjects than non-metropolitan schools, where non-metropolitan schools provided Agriculture and Horticulture, and Product Design and Technology in greater proportions than metropolitan schools. Students in metropolitan schools were also slightly more likely to have access to Food and Technology, and students in non-metropolitan schools slightly more likely to have access to Systems Engineering.

Table 3 shows the enrolment proportions in VCE technology subjects in schools where each subject is offered by school location. This shows the design technologies tend to attract higher enrolment proportions than the digital technologies and engineering. Not only are non-metropolitan schools more likely to provide Agricultural and Horticultural Studies, Product Design and Technology, and Systems Engineering, when they are provided, students in non-metropolitan schools enrol in higher proportions. Despite Food and Technology being more likely to be offered in metropolitan schools, where it is offered in non-metropolitan schools students enrol in greater proportions. Also, despite digital technologies being less likely to be provided in non-metropolitan locations, these students enrol in similar proportions to their metropolitan counterparts.

Table 4 shows the range and mean of Year 12 study scores achieved in technology subjects in all schools, metropolitan schools and non-metropolitan schools across the 3 years of the study. It shows that mean study scores in metropolitan schools and non-metropolitan schools are similar in most subjects. However, there are three subjects with large differences in mean study score by location. Metropolitan schools achieve higher scores in both

<p>| Table 3 | Enrolments in VCE technology subjects as a proportion of all VCE subject enrolments by school location |
|-----------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
|                             | All schools | Metropolitan schools (N = 164) | Non-metropolitan schools (N = 122) |
|                             | Mean (range) | Mean (range) | Mean (range) |
| <strong>Digital technology subjects</strong> | | | |
| Year 12 Algorithmics (HESS) | 0.3% (0.0–1.1%) | 0.4% (0.6–1.1%) | 0.2% (0.0–0.3%) |
| Year 11 Information Technology | 1.8% (0.6–7.9%) | 1.9% (0.6–7.9%) | 1.6% (0.0–7.3%) |
| Year 12 Computing: Informatics | 1.7% (0.0–8.6%) | 1.8% (0.0–8.6%) | 1.6% (0.1–8.2%) |
| Year 12 Computing: Software Development | 0.9% (0.0–5.4%) | 0.9% (0.6–5.4%) | 0.9% (0.0–3.4%) |
| <strong>Design technology subjects</strong> | | | |
| Year 11 Agricultural and Horticultural Studies | 2.1% (0.0–6.1%) | 1.6% (0.1–5.2%) | 2.2% (0.0–6.1%) |
| Year 12 Agricultural and Horticultural Studies | 2.2% (0.0–4.8%) | 0.8% (0.0–2.1%) | 2.4% (0.1–4.8%) |
| Year 11 Food and Technology | 2.5% (0.0–17.4%) | 2.0% (0.0–5.8%) | 3.2% (0.0–17.4%) |
| Year 12 Food and Technology | 2.5% (0.1–13.0%) | 2.0% (0.1–7.0%) | 3.1% (0.1–13.0%) |
| Year 11 Product Design and Technology | 2.5% (0.0–17.4%) | 1.6% (0.0–5.1%) | 3.6% (0.0–17.4%) |
| Year 12 Product Design and Technology | 2.4% (0.0–10.2%) | 1.6% (0.0–6.1%) | 3.3% (0.1–10.2%) |
| <strong>Engineering subjects</strong> | | | |
| Year 11 Systems Engineering | 1.4% (0.0–8.0%) | 1.0% (0.6–3.2%) | 2.0% (0.6–8.0%) |
| Year 12 Systems Engineering | 1.5% (0.0–4.0%) | 1.1% (0.6–2.9%) | 2.0% (0.6–4.0%) |</p>
<table>
<thead>
<tr>
<th></th>
<th>All Schools</th>
<th>Metropolitan schools</th>
<th>Non-metropolitan schools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (range)</td>
<td>N</td>
</tr>
<tr>
<td><strong>Digital technology subjects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algorithmics (HESS)</td>
<td>13</td>
<td>31.46 (23.71–41.00)</td>
<td>9</td>
</tr>
<tr>
<td>Computing: Informatics</td>
<td>162</td>
<td>28.27 (14.50–47.00)</td>
<td>101</td>
</tr>
<tr>
<td>Computing: Software Development</td>
<td>128</td>
<td>28.64 (13.50–44.00)</td>
<td>81</td>
</tr>
<tr>
<td><strong>Design technology subjects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural and Horticultural Studies</td>
<td>29</td>
<td>29.54 (12.00–40.00)</td>
<td>3</td>
</tr>
<tr>
<td>Food and Technology</td>
<td>231</td>
<td>28.71 (14.25–41.00)</td>
<td>136</td>
</tr>
<tr>
<td>Product Design and Technology</td>
<td>190</td>
<td>27.42 (9.32–50.00)</td>
<td>103</td>
</tr>
<tr>
<td><strong>Engineering subjects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systems Engineering</td>
<td>75</td>
<td>29.07 (18.95–50.00)</td>
<td>41</td>
</tr>
</tbody>
</table>
Computing: Software Development and Product Design and Technology. Non-metropolitan schools earn better results in Agriculture and Horticulture, though it should be noted that only three metropolitan schools ran this subject during the study period.

**VCE technology subjects and SES**

Table 5 shows the percentage of schools providing each of the VCE technology subjects by SES quartile. There are clear differences in the availability of digital technology subjects between the highest and lowest SES schools. Students attending the lowest SES schools are most likely to have Year 11 Information Technology and Year 12 Computing: Informatics available to them, while students from the highest SES schools are most likely to have access to Year 12 Computing: Software Development, and Year 12 Algorithms. Patterns of provision are different for Design Technology and Engineering subjects. The Agricultural and Horticultural Studies subjects, Product Design and Technology subjects, and Systems Engineering subjects are more likely to be available in second and third quartile SES schools, and less likely to be available in both highest and lowest SES quartile schools. Food Technology subjects seem to be provided at the same rate independent of SES.

Table 6 shows the proportion of enrolments in each of the technology subjects, at schools that offer these subjects, by SES quartile. Enrolment proportions in digital technologies varied in a similar pattern to subject provision in most subjects. Lower SES schools had higher enrolment proportions for Year 11 Information Technology and Year 12 Computing: Informatics, while the highest SES schools had the highest enrolment proportions for Year 12 Algorithms. While the rate of provision of Year 12 Computing: Software Development varied considerably with SES, the enrolment proportions in this subject did not. In the design technologies and engineering the patterns of enrolment did not tend to match the patterns of subject provision. While the lowest SES schools were least likely to provide Product Design and Technology, where it was provided the enrolment proportion was higher than the highest SES schools. Year 12 Agriculture was least likely to be offered by the lowest SES schools, yet where it was offered those schools had the highest enrolment proportions. Systems Engineering was provided by low SES schools at a rate far below the second and third SES quartile schools, however the enrolment proportions where not dissimilar across these three quartiles. Although food technology was provided at a similar rate in each SES quartile, enrolment proportions were considerably lower in the highest SES schools than the other quartiles. Finally, though Systems Engineering was provided by the highest and lowest SES schools at a similar rate, the highest SES schools had the lowest enrolment proportions by far.

Table 7 shows school’s mean study scores in each of the Year 12 technology subjects by SES quartile. In all subjects except Agricultural and Horticultural Studies and Systems Engineering, mean study score increased as SES quartile increased. In Systems Engineering the scores of the first two quartiles were lowest and scores increased from there into the third and fourth quartile. In Agricultural and Horticultural studies the lowest SES schools achieved highest and the highest SES schools achieved lowest however this was based on four and three schools respectively. Given these low numbers this trend may not be a reliable indicator of general performance.

Table 8 provides data about the relationship between SFOE and achievement level by listing Spearman’s rho correlation coefficients for each subject, across all schools, metropolitan schools, and non-metropolitan schools respectively. It shows there is a small positive linear correlation between SES and achievement for most subjects, with a large
<table>
<thead>
<tr>
<th>Table 5</th>
<th>Variance in the proportion of schools providing VCE technology subjects during the study period, by SES quartile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st quartile (N = 71)</td>
</tr>
<tr>
<td><strong>Digital technology subjects</strong></td>
<td></td>
</tr>
<tr>
<td>Year 12 Algorithms (HESS)</td>
<td>0–1%</td>
</tr>
<tr>
<td>Year 11 Information Technology</td>
<td>62–79%</td>
</tr>
<tr>
<td>Year 12 Computing: Informatics</td>
<td>54–65%</td>
</tr>
<tr>
<td>Year 12 Computing: Software Development</td>
<td>15–21%</td>
</tr>
<tr>
<td><strong>Design technology subjects</strong></td>
<td></td>
</tr>
<tr>
<td>Year 11 Agricultural and Horticultural Studies</td>
<td>0–4%</td>
</tr>
<tr>
<td>Year 12 Agricultural and Horticultural Studies</td>
<td>3–4%</td>
</tr>
<tr>
<td>Year 11 Food and Technology</td>
<td>65–75%</td>
</tr>
<tr>
<td>Year 12 Food and Technology</td>
<td>55–68%</td>
</tr>
<tr>
<td>Year 11 Product Design and Technology</td>
<td>46–54%</td>
</tr>
<tr>
<td>Year 12 Product Design and Technology</td>
<td>39–41%</td>
</tr>
<tr>
<td><strong>Engineering subjects</strong></td>
<td></td>
</tr>
<tr>
<td>Year 11 Systems Engineering</td>
<td>20–21%</td>
</tr>
<tr>
<td>Year 12 Systems Engineering</td>
<td>14–18%</td>
</tr>
</tbody>
</table>
Table 7  Comparison of schools’ achievement levels in VCE Year 12 technology subjects, where results were available for 2014, 2015 and 2016, by SES quartile

<table>
<thead>
<tr>
<th></th>
<th>1st quartile</th>
<th>2nd quartile</th>
<th>3rd quartile</th>
<th>4th quartile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (range)</td>
<td>N</td>
<td>Mean (range)</td>
</tr>
<tr>
<td><strong>Digital technology subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algorithmics (HESS)</td>
<td>1</td>
<td>28.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Computing: Informatics</td>
<td>55</td>
<td>27.00 (20.32–36.33)</td>
<td>41</td>
<td>28.84 (22.25–47.00)</td>
</tr>
<tr>
<td>Computing: Software Development</td>
<td>21</td>
<td>27.25 (18.20–36.00)</td>
<td>32</td>
<td>27.58 (14.50–43.00)</td>
</tr>
<tr>
<td><strong>Design technology subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural and Horticultural Studies</td>
<td>4</td>
<td>30.94 (26.75–39.00)</td>
<td>9</td>
<td>29.58 (20.14–40.00)</td>
</tr>
<tr>
<td>Food and Technology</td>
<td>53</td>
<td>25.93 (14.25–32.93)</td>
<td>64</td>
<td>28.17 (18.50–35.00)</td>
</tr>
<tr>
<td>Product Design and Technology</td>
<td>37</td>
<td>25.52 (9.32–35.00)</td>
<td>54</td>
<td>27.04 (11.67–41.50)</td>
</tr>
<tr>
<td><strong>Engineering subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systems Engineering</td>
<td>14</td>
<td>27.44 (20.38–33.90)</td>
<td>24</td>
<td>27.43 (21.08–32.79)</td>
</tr>
</tbody>
</table>
positive correlation in Food and Technology, and a negligible correlation in Agricultural and Horticultural studies. However, when metropolitan schools are considered separately, these correlations strengthened in all but Computing: Software Development. Conversely, in non-metropolitan schools, the correlations between SES and achievement are weaker in all subjects suggesting that SES has less of an impact on achievement in technology subjects in rural and regional schools.

**Discussion**

This study sought to explore the relationship of school location and socioeconomic status to the provision, uptake of, and achievement in technology subjects in Victorian government secondary schools. It used data routinely collected by the Victorian DET from all secondary schools offering VCE technology subjects in 2014, 2015 and 2016. Three outcome variables were considered: the VCE technology subjects provided by each school, the school’s average enrolment proportion in these subjects across these 3 years, and the school’s average study score in each subject across the 3 years. The findings offer insights into the impact of location and SES on engagement and achievement in VCE technology, however additional research is required to reveal why these relationships exist. Further, this study does not account for the contribution potentially made by student characteristics, such as gender or ethnicity, known to impact on student participation and achievement in technology subjects (e.g. Kennedy et al. 2018; NAEP 2014).

As the impact of school location upon engagement and performance in technology subjects is relatively unexplored in the literature, this paper offers new insights in this area. It is possibly unsurprising, given community context and learning opportunities available in rural and regional areas, that the design technology subjects of Agricultural and Horticultural Studies, and Product Design and Technology are more likely to be offered in non-metropolitan schools than metropolitan schools. The finding that the provision of Digital technology subjects is lower in non-metropolitan schools is particularly concerning, given...
the increasing demand for digitally literate employees in rural industries (Rural Australia Institute 2016). The reason for this disparity is not immediately apparent in these findings, given the enrolment proportions and achievement levels in the digital technology subjects are similar in metropolitan and nonmetropolitan schools, indicating that nonmetropolitan students are similarly drawn to, and capable of achieving well in, these subjects. Potentially the difference may be partly explained by the difficulties noted in recruiting qualified STEM teachers to rural and regional schools (Lyon et al. 2006) potentially leaving rural schools unable to staff Digital technology classes.

This study produced some surprising findings around the impact of SES on technology subject provision and participation. While previous research suggests that participation in design technology subjects are associated with low SES backgrounds (Elsworth et al. 1999; Mullis et al. 1998) this study reveals different trends, particularly when considering the schools in the lowest SES quartile. The lowest quartile SES schools were the least likely to provide access to the Product Design and Technology subjects, and these schools had the second lowest enrolment proportions in these subjects, just ahead of the enrolment proportions in the highest SES schools. In all other design technology subjects the schools in the lowest SES quartile had lower provision rates and enrolment proportions than schools in the second lowest SES quartile. This appears counter to findings of previous studies that showed low SES is associated with participation in more practical and technical subjects (Davies et al. 2008; Elsworth et al. 1999; Mullis et al. 1998). A potential explanation for the low provision and enrolment rates of design technology subjects in the lowest SES schools may be associated with the cost of delivering and participating in these subjects. These subjects require schools to have and maintain an extensive range of equipment that may be beyond the reach of lower SES schools where communities are less able to contribute to the school’s discretionary spending. Further, students are often required to pay for the materials they use in these subjects, potentially precluding the participation of many students from low SES backgrounds. So, though research suggests students from lower SES backgrounds are more likely to be interested in these design technology subjects (Mullis et al. 1998), this study shows that in Victoria they are actually less likely to study these subjects.

The current study also found that, in general, lower SES schools tend to have higher enrolment proportions in digital technology subjects, aligning with previous research findings that lower SES students were more likely to enrol in computing subjects (Dar and Getz 2007; Elsworth et al. 1999). However, there are some differences between the provision of the various digital technology subjects. Year 11 Information Technology and Year 12 Computing: Informatics are more likely to be offered in the lowest SES schools, and these schools also have the highest enrolment proportions. However, Year 12 Computing: Software Development is offered most often by the highest SES schools, despite the fact that enrolment proportions in this subject do not vary considerably by SES quartile. Why this should be the case is not apparent, however this finding flags a potential equity issue and warrants further research.

This study also contributes to the weight of evidence behind another equity issue in technology education, that of SES impacting on student achievement (ACARA 2014; NAEP 2014; Rizhaupt et al. 2013). In the current study, in almost all VCE technology subjects, as school SES quartile increased, so did the average achievement level. This trend was also observed in VCE Science and Mathematics in the other studies in this project investigating engagement and performance in senior secondary school STEM that the current study belongs to (Murphy 2018a, b). Further, calculation of Spearman’s rho correlations suggest that school SES is somewhat predictive of student achievement in technology
subjects, but more predictive in metropolitan schools than in non-metropolitan schools. Again, similar correlations were observed in VCE Mathematics (Murphy 2018a) and Sciences (Murphy 2018b), however they tended to be larger in these disciplines than in VCE technology subjects, suggesting that SES has less impact on student performance in technology than in the other STEM disciplines.

These findings have significant practical implications for policy makers and schools, as well as pointing the way for further research opportunities. The finding that students attending the lowest SES schools have relatively poor access to design technology subjects is a social justice issue. Students from lower SES backgrounds are more likely to pursue practical and technical career pathways (Mullis et al. 1998) and are less likely to have access to the resources to pursue careers requiring further study at University (Gore et al. 2015). Despite this, these findings show students attending the lowest SES schools have poor access to the senior secondary subjects that allow them to build practical design technology skills. Schools and school departments may need to consider ways to make these subjects more accessible to students in Victoria’s lowest SES schools. Also concerning are the differences in provision of the digital technology subjects in schools of different SES. It is arguable that Computing: Software Development, with its focus on programming including creating simple games, is a more relatable subject to adolescents than Computing: Informatics, which focuses on digital data management, yet the former is far more frequently offered to students from high SES backgrounds, while the latter is more frequently made available to students at the lowest SES schools. Further research is required to explore the reasons for this difference and the potential implications for student engagement and aspiration development in digital technologies. Continued research and resourcing effort is also required to redress the imbalance in achievement between low SES schools and high SES schools in technology. Finally, the relatively poor access to the digital technology subjects in non-metropolitan schools needs to be addressed, given that strong digital literacy is required in a broad range of careers and other facets of life (Rural Australia Institute 2016; Webb et al. 2017).

Conclusion

This study reveals differences in participation and achievement in technology subjects by location. While there is little difference in the academic performance of students from metropolitan or non-metropolitan locations in technology subjects, there were notable differences in participation. Students in rural and regional areas were more likely to have access to Agricultural and Horticultural Studies, and Product Design and Technology, and were more likely to enrol in each of the design technology and engineering subjects than students attending metropolitan schools. However, while non-metropolitan students enrolled in the digital technology subjects at a similar rate to metropolitan students, they were much less likely to have these subjects provided in their schools. This finding sets a challenge to ensure that rural and regional schools are adequately resourced and staffed so that non-metropolitan students have equitable access to opportunities to develop the digital technology skills integral to many careers.

This study also flags a challenge to ensure students from lower SES schools are provided equal opportunities to participate and achieve in all technology subjects. Students from lower SES schools tended to perform more poorly in technology subjects than students from high SES backgrounds, aligning with findings from previous studies. However,
this study revealed new knowledge related to SES and access to senior technology subjects. It was found that the lowest SES schools were the least likely to offer five of the six design technology subjects and two of the four digital technology subjects. This is concerning given that previous research shows that students from low SES backgrounds are most likely to pursue technical and practical careers (Mullis et al. 1998).

References


Appendix M. Murphy (2019d)

Murphy

Practices contributing to Mathematics success in a low socioeconomic rural Victorian school

Sieve Murphy
Charles Sturt University
<smurphy@csu.edu.au>

Mathematics education is seen as a right for all children, and important to ensure a prosperous future. However, in Australia and other nations, rural students perform less well in mathematics, and are less likely to pursue advanced mathematics. This paper presents a case study of an Australian rural school that has high engagement and achievement in senior mathematics, despite its setting. The study uses a practice architectures framework to explore the activities and facilitatory elements that have likely contributed to the school’s mathematics success. Personalising learning, valuing mathematics, building teacher capacity, and linking to careers, were all associated with the school’s higher than expected mathematics performance.

In our technocratic world, a deep understanding of mathematics is seen as a right for all citizens (Center for Curriculum Redesign, 2013), and there is a call for a workforce with strong mathematics skills and associated skills in data analysis, coding and engineering (Australian Industry Group, 2015; Morgan & Kirby, 2016). At the same time, many nations, including the United States of America, the United Kingdom and Australia, have experienced low student participation and achievement in mathematics (Marginson et al., 2013). This deficit is even more pronounced amongst rural students. In Australia, metropolitan Year 8 students significantly outperform their non-metropolitan counterparts in mathematics (Thomson, Wernert, O'Grady, & Rodrigues, 2017). In Victoria, when completing the Victorian Certificate of Education (VCE), rural students are less likely to participate in advanced mathematics subjects, such as Specialist Mathematics and Mathematical Methods, and more likely to enrol in elementary mathematics subjects, such as Further Mathematics (Murphy, 2018). Further, metropolitan students outperform students attending rural schools in all VCE mathematics subjects (Murphy, 2018).

Research suggests the reasons for this deficit are varied. Some studies suggest rural students feel less competent and less engaged in mathematics, and that their mathematics teachers are less supportive (Harder, 2011). Rural students and their parents tend to have lower educational aspirations (Centre for Education Statistics and Evaluation, 2013), so may be less likely to pursue mathematics as a pathway to further study. It is also difficult to recruit and retain qualified mathematics teachers in rural areas, and to provide these teachers with appropriate professional learning (MePhta & Tobias, 2011). There are strategies that are known to be effective in addressing issues of student engagement in mathematics and mathematics teacher capacity, such as differentiated instruction (Prast, Van de Weijer-Bergsma, Kroesbergen, & Van Luijt, 2015), engaging pedagogical repertoires (Attard, 2014), and models of professional learning in mathematics (Watson, Beswick, & Brown, 2012). However, there is scant evidence regarding what may be effective in improving school-wide mathematics education in rural contexts.

This paper addresses this shortfall. It presents a case study of a rural Victorian school, referred to as Sweeping Plains College (SPC) in this paper, that has sustained high participation and high achievement in VCE mathematics. It explores the mathematics education practices of SPC, addressing the research question, “What mathematics education practices might have contributed to the sustained mathematics success of SPC?”

Method

Conceptual Framework

In order to explore the complex interplay of the various practices influencing the school’s mathematics success, practice architecture was used as a conceptual framework to guide data collection and analysis. Practice architecture sees practices as comprised of ‘saying’, ‘doing’ and ‘relating’ actions (Kemmis, 2008). These actions influence, and are influenced by, the cultural-discursive structures of language, the material-economic structures of work and resourcing, and the socio-political structures of power and relationships, that make up practice architectures (Kemmis, 2008). Using a practice architecture lens, the various activities possibly contributing to SPC’s mathematics success were examined, as well as the structures that constrain and enable these activities.

Case Selection

Schools vary in their average enrolment proportions and achievement levels in VCE mathematics subjects (Murphy, 2018). Using Year 12 VCE participation and achievement data, SPC was selected for study as a rural school with high mean mathematics enrolment proportions (out of all VCE subjects undertaken), and high mathematics study scores (standardised scores out of 50 with a median of 30) (see Table 1). SPC’s enrolment proportions and study scores in mathematics were consistently high across all three years.

<table>
<thead>
<tr>
<th>Mathematics Subject</th>
<th>Sweeping Plains College</th>
<th>All Victorian government schools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean enrolment proportion</td>
<td>Mean study score&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Further Mathematics</td>
<td>11.02%</td>
<td>31.90</td>
</tr>
<tr>
<td>Mathematical Methods</td>
<td>7.87%</td>
<td>30.40</td>
</tr>
<tr>
<td>Specialist Mathematics</td>
<td>2.36%</td>
<td>34.00</td>
</tr>
</tbody>
</table>

<sup>a</sup> VCE study scores are standardised scores out of 50 with a median of 30.

Participants

The principal, Ken, as well as six teachers teaching across mathematics, science and technology subjects at various year levels (Karen, Adrian, Lilly, Paul, Georgia, and Craig), gave consent to be interviewed. Six female and six male students currently studying VCE Science, Technology, Engineering and Mathematics (STEM) gave consent to be interviewed.

Data Collection

Data were collected from various sources. School level quantitative data were obtained about participation and achievement in VCE subjects in 2014, 2015 and 2016 from the Victorian Department of Education and Training (DET). Publicly available National Assessment Program – Literacy and Numeracy (NAPLAN) data for the relevant cohorts were extracted from the MySchools website. Qualitative data were gathered during site visits through semi-structured interviews with participants (Gideon & Moskos, 2012). The
paper reports on one aspect of a project investigating rural school STEM success. The teachers and the principal were interviewed individually, and were asked open-ended questions about perceived contributors and impediments to STEM education success at the school. Students were interviewed as a group and asked open-ended questions about their learning experiences and participation in STEM. All interviews took place in the school’s careers room and varied in length from 20 – 40 minutes. The interviews were recorded and transcribed, and the transcripts were used for analysis. The school’s annual report, college profile and philosophy, student subject selection booklet, and timetable were also collected for analysis. The researcher also toured the school accompanied by the principal, taking field notes and photographs of resources, display and facilities.

Case Analysis

Using a practice architecture conceptual framework, an explanation-building approach to analysis was employed for the case analysis (Yin, 2014), where a set of causal links were sought to explain how and why SPC had achieved its mathematics education success. Qualitative data were analysed using thematic analysis (Braun & Clarke, 2006). Data were coded using both deductive and inductive themes (Braun & Clarke). Initially data were coded into practice activity (sayings, doings, or relating) or practice architecture (cultural-discursive, material-economic, or socio-political) categories. Following this, through iterative engagement with data coded as relating to practices and practice architectures, inductive themes were identified, a process Braun and Clarke described as “organic thematic analysis” (p. 741). Six themes emerged through this process: differentiated instruction in mathematics, valuing mathematics, building teacher capacity, careers education, vocational education and training, and community connections. The quantitative data were analysed descriptively to corroborate and extend understandings gained from the qualitative data sources. The use of multiple sources of qualitative and quantitative data allowed for triangulation of findings (Yin, 2014), enhancing the overall credibility of the study (Tracy, 2010).

Case Study

School Context

SPC is a rural co-educational P-12 school with 136 students in 2016, 41% of whom are in the primary school, and 59% in the secondary school. 5% of students identified as Indigenous Australian or Torres Strait Islander, and 1% had a language background other than English. The Index of Community Socio-Educational Advantage for the school was 963 (MySchool website), below the standardised national mean of 1000. SPC serves a stable farming community more than 200 kilometres from Melbourne and more than 100 kilometres from the closest regional city. The nearest independent secondary school is approximately 1 hour and 20 minutes’ drive away; however, there are five other government secondary schools within a 30 minute drive. These government schools collaborate as part of a network, sharing resources including the Technical Trade Centre (TTC) built on SPC’s site.

Cohort Profile

From 2014-2016, a total of 25 students completed VCE at SPC, with a mean study score of 31.7 across all Year 12 VCE subjects. Table 1 shows that this cohort’s achievement levels were well above the state average in all mathematics subjects. The enrolment proportions were well above state average in Mathematical Methods, and Specialist Mathematics, and

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slightly below state average in Further Mathematics, counter to the trend of rural students choosing less advanced mathematics (Murphy, 2018). NAPLAN data show that in Year 5 this cohort’s results were similar to the state average in numeracy (409 compared to 402) but above state average in Year 7 (571 compared to 553) and in Year 9 (610 compared to 604). SPC attracts additional enrolments at the beginning of secondary school, causing an average 67% increase in student numbers from Year 6 to Year 7, which may account for the improvement in Year 7.

School Mathematics Programs

SPC’s mathematics education is delivered through non-integrated mathematics classes, similar to other Australian schools (Marginson et al., 2013). However, SPC’s students spend more time studying mathematics. In the primary school, SPC students study 280 hours of numeracy each year, compared to an average of 202 hours for Australian Year 4s, and from Year 7 to 9 they study 187 hours of mathematics, whereas the average Australian Year 8 student studies 139 hours (Thomson et al., 2017). Given the small school size, there is only one class group at each year level. Year 9 and 10 mathematics lessons are taught together by two teachers, with students grouped by ability and studying either a standard mathematics program or accelerated VCE General Mathematics. Each year from 2014-2016 SPC ran all three Year 12 mathematics subjects shown in Table 1, something increasingly rare in rural schools (Murphy, 2018).

Mathematics Education Practices contributing to SPC’s mathematics success

While the broader research project this case study forms part of explored STEM education, thematic analysis of SPC interviews revealed a common focus on mathematics education. Of the themes to emerge, two - differentiation in mathematics, and valuing mathematics - were specific to mathematics education. Three practices, teacher capacity, careers education, and vocational education and training, were seen as impacting significantly on mathematics education at the school. The following sections explore practices captured by these five themes.

Differentiation in Mathematics

SPC teachers used a variety of strategies to differentiate learning to meet each student’s needs in mathematics. From Year 4 on, the mathematics program involves students taking ownership of their learning and working in flexible arrangements at their own ability level and pace. Karen explained, “They’re building at a very early age that knowledge of, ‘okay there is more to learn and I can’, and building that independence and actually working towards achieving their goals and learning more and more’.

Pre-testing is used to help students set learning goals and they then access their learning program via Google Classroom. The teachers make use of online videos, software, activities, games and small group instruction to resource the program and support student learning. Karen said, “It’s all up on the Google classroom page and the kids just follow through. So on [the] Google classroom page it says watch the clip below, and if they understand that they can just go on and do the work. If they don’t understand it, they’ll come and seek support from one of the teachers in the room. Or it might say you need to go and do a focus with the teacher”.

Student learning is monitored publicly. Karen described this, “All their learning intentions [are] on a grid for the kids to see. It’s a visual thing with their name on the bottom, they colour in what they can do...and their goals are in a light colour...And they just go from one skill to the next as they progress...So today when I wrote on the board, I
had I think about nine different things that people were doing in a classroom of... about 20 kids”.

Several students commented positively about the differentiated mathematics instruction in the middle years. One student said, “You wouldn’t have to be doing things with kids that were at a lower level of maths and you would be able to learn the things that you needed to rather than keep going over the same sort of stuff that another group wouldn’t be at”.

In Year 10 many students at SPC accelerate into Year 11 level VCE General Mathematics. This transition option is seen as providing a good opportunity for advanced students, as well as facilitating more effective support for students finding mathematics more difficult. Students continue to receive differentiated support through their senior years, however, this is more often through additional out-of-class assistance.

Both teachers and students felt that the small size of the school and STEM classes, particularly in VCE, made understanding and responding to each student’s learning needs more achievable. Somewhat related, the closeness of relationships between staff and students and families at SPC was seen as contributing positively to the school’s mathematics education success. Adrian commented, “Because of that intimacy of the relationships between the students and the staff and the whole community, just supporting everybody and being able to know that if you want to do something there’s always people there to help you, and support”.

Valuing Mathematics

The teachers also invest significant effort into encouraging students and their families to value mathematics and mathematics education. Regular mathematics columns in the school newsletter promote mathematics activities and the achievement of students. Fortnightly mathematics awards are presented at school assemblies for effort and achievement. Students are supported to participate in a diversity of external mathematics competitions and activities. Every few years SPC hosts a whole school mathematics day. These activities are seen as enhancing the valuing of mathematics by students and parents.

The utility value of mathematics education is also emphasised. There is a focus on explaining how each aspect of mathematics is used in the real world. Adrian said, “I think at teachers, when we teach maths... we always try to use real-life situations for problem-solvers”. Karen and Craig spoke about explicitly writing on the board why students are learning the mathematics that is the focus of that particular lesson. Various teachers spoke about adjusting their mathematics learning programs to respond to student interest in taxation, finances and farming, noting that students saw the relevance of these real world contexts and thus were “really engaged and interested”. The students felt this practice made the mathematics more relevant and easier to learn. One student said, “She’d relate it back to real life as well so it made it more relatable”. Another comment was, “He just related it back to real life, which always makes things a lot easier to remember”.

In addition to exploring the real world applications of mathematics, the staff also emphasise the utility value of studying mathematics for accessing further study and/or particular careers. Georgia offered this reflection on this pragmatic approach, “Whatever you do you’re going to need the maths, so there’s got to be something that you have to, not necessarily enjoy, but at least persevere with... the fact that most of our kids do VCE maths, ... the majority of them can see that maths is going to be involved in their job, some sort of maths”.

Teacher Capacity

The mathematics teachers at the school are regarded as strong, passionate educators. Karen said, “You’ve got to have people on the ground that are passionate and can share their passion with the kids I think, yeah”. A student, describing her previous mathematics
teachers said, “They were just very well educated themselves and just really good at explaining to other students what they were trying to get”.

The school invests in building the capacity of its mathematics teachers through a range of mechanisms. The mathematics staff regularly meet as a numeracy professional learning community (PLC) where they engage in targeted professional learning activities to meet school needs. Sometimes the PLC explores particular mathematics content, such as word problems and numeracy fluency; at other times they consider the mathematics learning needs of particular students. Karen illustrated this, “This is the student I’ve got and this is their background and this is what I’m struggling with... What I want is an idea about what I can do, and things like that”. The numeracy PLC also strategically pursue external professional development to help meet the needs of their students; for example, having multiple staff trained in the Quicksmart program in response to concerns about the numeracy fluency of their middle school students.

Teachers are also well supported to pursue their own professional learning (PL) interests. Ken said, “We encourage our staff to undertake a lot of PD, particularly senior teachers, maths teachers, et cetera”. Teachers agreed they had good support to attend PL, and Georgia noted that accessing PL was much easier at SPC than at her previous school. Several teachers cited PL they had recently attended, but they also noted the difficulty of time and travel associated with accessing this PL. When available, the mathematics team engages with closer PL opportunities organised by schools in their network. There is an obligation on those who attend professional development to report back through the numeracy PLC. There are also informal PL opportunities. Georgia noted, “If we have questions, [we] can get together ‘cause there’s only a handful of us anyway.” Timetable arrangements also provide opportunities for team teaching in mathematics from Years 4-6 and again in Year 9 and 10. Further, the flow of numeracy expertise between the primary and secondary schools is enhanced by some mathematics teachers teaching in both areas.

Careers Education and Vocational Education and Training (VET). Thematic analysis identified two further themes contributing to mathematics education at SPC: Careers education and VET. Both these themes were seen as particularly contributing to student engagement and participation in mathematics. The school runs an extensive careers program beginning in Year 7. Both staff and students spoke about this program contributing to the students’ understanding of mathematics pathways and careers. Ken explained, “That really, I think, supports students when they’re making choices for subjects entering into VCE, there’s great knowledge there and recommendation regarding the need for your maths subjects for example, depending on what their career choices might be.”

The extensive VET program offered by the school in the TTC was also seen as highlighting the utility value of mathematics as well as reinforcing numeracy skills. All Year 9 and 10 students spend one day each week in the TTC, where they choose from an array of subjects, most of which are STEM related such as Agriculture, Allied Health, Animal Studies, Automotive, Building and Construction, Engineering, Games Design, Kitchen Operations, and Textiles. Paul spoke about the role of mathematics in the VET program, “You’ve got to include numeracy everywhere... Numeracy is paramount. So it’s imperative that the students, especially in engineering, have numeracy competency”.

Participants also referred to farming and other local industries highlighting the utility value of mathematics for students. Interestingly, some also highlighted SPC’s isolation and decreasing local employment opportunities as a potential motivator for students to do well in mathematics in order to seek study and employment elsewhere.
Discussion and conclusion

SPC is a school that has sustained high enrolment proportions and achievement levels in senior mathematics subjects, despite its rural location. Practice architecture was used as a conceptual framework for analysing the educational practices associated with this mathematics success. This analysis produced five key themes related to mathematics education: differentiation in mathematics, valuing mathematics, teacher capacity, careers education, and vocational education and training.

SPC students spend many more hours studying mathematics than the national average (Thomson et al., 2017), although, in the literature, there appears to be no association between instructional time and achievement in mathematics in Australia (Baker, Fabrega, Galindo, & Mishook, 2004). The particular practices at SPC appear to have a positive impact on its students’ achievement and engagement in mathematics. Differentiated instruction in mathematics, as implemented at SPC, has been shown to impact positively on student achievement (Prast, Van de Weijer-Bergsma, Kroesbergen, & Van Luit, 2018). The cycle of pretesting, goal setting, individualised instruction and practice, and post-testing in middle year’s mathematics at SPC matches the cycle of differentiation espoused by mathematics education experts (Prast, Van de Weijer-Bergsma, Kroesbergen, & Van Luit, 2015). In combination, the differentiated instruction at SPC, facilitated by embedded technology and incorporating student self-direction, combined with SPC’s practices highlighting the value of mathematics, might be viewed as an example of Attard’s engaging pedagogical repertoires for mathematics (Attard, 2014). More broadly, SPC’s practices build student self-efficacy, student valuing of mathematics, and parent interest in mathematics, all factors that are known to contribute to student engagement and ‘future intent’ towards mathematics (Martin, Anderson, Bobis, Way, & Vellar, 2012).

Recruitment difficulties and high turnover of mathematics teachers does not seem to have impacted SPC in recent years, as they have other rural schools (McPhan & Tobias, 2011), with several long-term mathematics teachers and the mathematics teachers regarded as strong educators by the school community. The mathematics teachers at SPC were seen by their students as strongly supportive, counter to Hardre’s (2011) findings regarding rural mathematics teachers. SPC’s numeracy PLC’s approach to professional learning includes many of the elements of effective mathematics PLC described by Wason, Beswick, and Brown (2012). PL in mathematics at SPC centres on the school’s students’ learning needs, as identified by the teachers who know them, and draws on external expertise as required. In addition to this collective approach, teachers are supported to pursue their own PL interests in mathematics.

A limitation of this study is that the entire cohort whose performance was the basis for choosing SPC for study was only 25 students. Although unlikely, it is possible that SPC’s ‘mathematics success’ was due to individual student rather than school based factors. However, even if this was the case, the identified practices provide a valuable illustration of how the mathematics engagement and achievement of this cohort was maintained and developed.

SPC is a case of a rural school where an array of mathematics practices appear to have contributed to very-high, sustained senior mathematics performance. Mathematics education, like all school practices, is comprised of a complex array of situated activities, and the cultural, material and social structures that shape them (Kemmis, 2008), which are likely to be unique to each school community. Given this, this case study does not describe a generalisable approach to be adopted by other schools. Rather it provides transferable insights into how mathematics education practices may be used to foster increased participation and achievement in senior mathematics education, particularly in small rural
schools. Further investigation of the mathematics practices in other successful rural schools, and comparing these to less successful rural schools, could deepen this understanding, offering more guidance to rural school practitioners and policymakers helping to close the mathematics performance gap between metropolitan and rural schools.

References


Appendix N. Murphy (2020)

Chapter 16

Motivating Rural Students in STEM: Practices Contributing to Student Engagement with STEM in Rural Victorian Schools

Steve Murphy

Abstract A significant but largely overlooked equity issue in STEM education is the relatively low engagement and performance of rural students in STEM. Students from rural schools tend to achieve more poorly in the STEM disciplines and are less likely to engage in further STEM study than their metropolitan counterparts. This chapter reports on findings of an Australian project examining STEM education success in rural Victorian government schools. The project investigated the STEM practices of four schools that consistently attracted higher enrolments and achieved stronger results in senior STEM subjects, compared with similar rural schools. This chapter presents a cross case synthesis of practices that appear to contribute to the STEM success of these schools, and discusses the findings in relation to theoretical models of motivation and academic emotion. The four rural schools employed a complex array of practices to improve student engagement in STEM, including: holding high expectations while providing generous support; place-based learning; STEM enrichment opportunities; and differentiated mathematics programs. While the practices employed are not restricted to rural schools, each school felt their rural nature facilitated these engaging practices.

16.1 Introduction

Students in rural schools perform more poorly than their urban counterparts in STEM. International and national testing suggests that Australian metropolitan students significantly outperform non-metropolitan students in mathematics, science, and information and communication technology (Thomson, De Bortoli, & Underwood, 2017; Thomson, Wernert, O’Grady, & Rodrigues, 2017). Studies of Year 12 participation and achievement in Victoria show that metropolitan schools have higher average enrolments and achievement levels than rural and regional schools in senior mathematics and science (Murphy, 2018a, 2018b). Metropolitan students are more likely to be interested in science, enjoy learning science, and see science as contributing to their future career (Thomson, De Bortoli, et al., 2017). Students in rural schools are less likely to prefer science to other subjects, and are less likely to enjoy science subjects (Lyons & Quinn, 2010).

The disparity between rural and metropolitan student’s achievement and engagement in STEM education is given some, but limited, attention in the various Australian jurisdictions’ STEM strategies (Murphy, MacDonald, Danaa, & Wang, 2018). The National STEM School Education Strategy (Education Council, 2015) clusters rural students with other groups experiencing inequity in STEM, noting, “Girls, students from low socio-economic status backgrounds, Aboriginal and Torres Strait Islander students, and students from non-metropolitan areas can be less likely to engage with STEM education and therefore have a higher risk of not developing high capabilities in STEM-related skills” (p. 4). This strategy also recognises the dearth of evidence about effective STEM education in Australian
contexts. It identifies five national actions, the fifth of which is to build a strong evidence base “to determine which approaches work best for different purposes and student cohorts” (p. 10). The research reported on in this chapter responds to a need for research into effective STEM education practices in rural schools.

This chapter reports on a multiple-case study of the STEM education practices of four relatively high STEM performing rural Victorian schools. This chapter presents a cross-case synthesis of practices associated with improved STEM engagement, addressing the question: What practices appear to contribute to student engagement in STEM education in high STEM performing rural schools?

16.2 Engagement in STEM

Despite a weight of evidence demonstrating that student dispositions towards STEM impacts on their achievement and ultimate pursuit of STEM careers, student disposition is given limited attention in Australian STEM education strategies (Murphy et al., 2018). Where it is, vague terms are used, such as engagement, interest and aspiration, with little explanation as to what they mean or how they can be achieved. This chapter defines STEM engagement as a student’s commitment to active involvement in STEM learning (Christenson, Reschly, & Wylie, 2012), with this engagement being behavioural, cognitive, and emotional (Fredricks, Blumenfeld, & Paris, 2004). Further, this engagement is driven by learner motivation and academic emotions in STEM.

There are several motivational models that have been found to be predictive of achievement, participation and aspiration in STEM (Murphy, MacDonald, Wang, & Dunaia, 2019). Expectancy-value theory (Eccles, 2009), particularly prominent in the literature, argues that student’s expectations of success in learning, and the value they attribute to this learning (task value), impacts on student effort, engagement, and student learning choices. Students’ expectation of success is strongly linked to their self-concept (their beliefs about their ability in a particular area) and their self-efficacy (their beliefs about their ability to complete a certain task) (Schunk, Pintz, and Meece, 2008). Student self-concept in STEM has been found to be predictive of achievement (Loou, 2017; Petersen & Hyde, 2017). The task value for a student may be impacted by attainment value (the importance of doing well on a task), interest value (the enjoyment to be gained by doing a task), utility value (the long-term usefulness of a task), and cost (the effort and emotional impact associated with the task) (Eccles, 2005). Similar to student’s self-concept, a student’s task value has been shown to be predictive of STEM learning engagement, subject choice and career aspirations (Guo, Parker, Marsh, and Morin, 2015; Guo, Marsh, Parker, Morin and Dicke, 2017).

Motivation is also theorised to be impacted upon by a student’s sense of autonomy, sense of relatedness, mind-set, and goal orientation (Carmichael, Muir & Callingham, 2017, Dweck & Leggett, 1998; Lazzardes & Rabbach, 2017; Wang & Holcombe, 2010). Autonomy supportive strategies, such as providing choice and welcoming student thoughts and feelings, have been found to be associated with higher motivation and engagement in mathematics (Carmichael et al., 2017), and higher motivation and achievement in science (Jungert & Koeser, 2015). Student perceptions of teacher care and support have also been linked with higher motivation and achievement in STEM (Wang & Holcombe, 2010). Students who believe that ability can be developed through effort rather than intelligence being unchangeable, have higher motivation and achievement in mathematics and science.

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In mathematics, secondary students pursuing mastery goals by focusing on developing their understanding and academic competence show improved participation, effort and persistence (Lazarides & Rubach, 2017).

Finally, student’s academic emotions have been found to impact on both student engagement and achievement in STEM. Negative emotions, such as anxiety, boredom and hopelessness, are inversely correlated with effort and achievement in mathematics (Larkin & Jorgensen, 2015). Conversely, positive emotions such as enjoyment, improve student persistence and lead to stronger achievement in STEM (Simon, Atulls, Dedic, Hubbard, and Hall, 2015).

16.3 Engagement in Rural Schools

While significant research attention has been given to participation in education in rural schools (Cavanagh, 2014), far less has been given to rural student motivation (Hardré, 2011). The literature that does exist highlights various factors that appear to engage rural students in education. Teacher characteristics, teacher support, and teacher-student relationships are all predictive of rural student self-concept and student interest in subjects (Goviella-Payne, Denny, Davis, Francis, & Jackson, 2015; Hardré & Sullivan, 2008; Hardré, Sullivan, & Crowson, 2009). The perceived utility value of content impacts on rural student effort, and personal learning goals and self-concept impacts on rural student interest and achievement in a subject (Hardré et al., 2009). It has also been argued that as rural students are closely tied to their immediate community, the local culture, resources, and role models also impact on student academic engagement (Hardré et al., 2009).

If the literature on student motivation in rural schools is scant, research investigating motivation in STEM in rural schools is rarer still. A study of a motivational model with rural Australian students found that persistence in mathematics was strongly correlated with students’ self-efficacy and valuing mathematics (Plenary & Heubeck, 2011). This study found that motivation in mathematics was lowest in middle secondary school, linked with low perceived utility value, before recovering somewhat in senior years. Hardré (2011) contrasted engagement in mathematics against other subjects in rural schools and found that students felt that maths was less engaging, that they were less competent in mathematics, and that mathematics teachers were less supportive. This study also found a disconnect between mathematics and science teachers’ perceptions of motivational factors and those of their students, with teacher instructional and interpersonal efforts to motivate students in these subjects not being received as intended.

16.4 Conceptual Framework

While it is acknowledged that a range of non-school factors impact on rural student engagement in STEM (Centre for Education Statistics and Evaluation, 2013), the research discussed in this chapter focused on the practices of educators and educational leaders believed to have contributed to engagement in STEM at four relatively high STEM performing rural schools. Each practice was seen to impact upon student motivation towards STEM and STEM education in different ways, and these could be aligned to the motivational constructs discussed in section 16.2. Ultimately, by motivating students in these ways, these
practices are assumed to contribute to student engagement with STEM learning, as depicted in Figure 16.1.

Fig. 16.1. The impact of various educator practices on domains of student motivation, leading to student engagement in learning

16.5 Method

This study adopts a holistic multiple-case design with a replication logic (Yin, 2014). Four rural schools with higher than expected student engagement and achievement in STEM were selected for study. They were first considered as individual cases, analysing qualitative and quantitative data collected about each school’s STEM education success through interviews, document analysis, observation, and interrogation of databases. Cross case analysis was then conducted to identify practices associated with STEM engagement across these schools.

16.5.1 Case Selection

Schools vary in their average enrolment proportions and achievement levels in Victorian Certificate of Education (VCE) STEM subjects (Murphy, 2018a, 2018b). The four schools selected for this study are rural schools whose Year 12 2014 to 2016 cohorts had higher mean STEM enrolment proportions (out of all subject enrolments) in Year 11 and in Year 12, and higher mean STEM achievement level in Year 12, than other rural schools in the same socio-economic status quartile (herein referred to as “like schools”). Mean data across three years was used to mitigate for potential cohort effects. The four schools’ mean enrolment
proportions and achievement levels, compared to the like school average, are shown in Table 16.1.

Table 16.1 Mean enrolment proportions and achievement levels from 2014-2016 at case schools and like schools

<table>
<thead>
<tr>
<th>School</th>
<th>Mean Year 11 STEM enrolment proportion</th>
<th>Mean Year 12 STEM enrolment proportion</th>
<th>Mean Year 12 STEM achievement level (study score out of 50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweeping Plains College (SPC)</td>
<td>4.9%</td>
<td>4.3%</td>
<td>32.22</td>
</tr>
<tr>
<td>Like school average</td>
<td>4.2%</td>
<td>4.2%</td>
<td>26.54</td>
</tr>
<tr>
<td>River Valley College (RVC)</td>
<td>4.8%</td>
<td>4.6%</td>
<td>26.33</td>
</tr>
<tr>
<td>Like school average</td>
<td>4.2%</td>
<td>4.2%</td>
<td>26.33</td>
</tr>
<tr>
<td>Coastal Secondary College (CSC)</td>
<td>4.5%</td>
<td>4.5%</td>
<td>26.55</td>
</tr>
<tr>
<td>Like school average</td>
<td>4.1%</td>
<td>4.1%</td>
<td>26.55</td>
</tr>
<tr>
<td>Alpine Secondary College (ASC)</td>
<td>4.7%</td>
<td>4.3%</td>
<td>28.66</td>
</tr>
<tr>
<td>Like school average</td>
<td>4.3%</td>
<td>4.3%</td>
<td>28.66</td>
</tr>
</tbody>
</table>

These four schools collectively represent the diversity of rural Victorian school contexts. All had secondary school enrolments of less than 300 students, and all were more than an hour’s commute to the nearest regional centre, and at least two hours from Melbourne, the state capital. RVC and SPC are P-12 schools, while ASC and CSC are straight secondary colleges. ASC has an Index of Community Socio-Economic Advantage (ICSEA) above the national average, CSC and RVC’s ICSEAs are only just below the national average, and SPC’s ICSEA is well below the national average (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2019). The schools serve communities with a diversity of dominant industries, including cereal production, beef, dairy, wool, forestry, and tourism.

16.5.2 Participants

At each school, principals and all teachers of secondary STEM subjects were invited to participate in interviews about the school’s STEM success. Current Year 12 students studying at least one STEM subject were invited to participate in group interviews. The numbers of participants at each school who gave consent and were able to participate in interviews are listed in Table 16.2.

Table 16.2 Type and number of participants interviewed at each school

<table>
<thead>
<tr>
<th>School</th>
<th>Principals</th>
<th>STEM teachers</th>
<th>Year 12 students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweeping Plains College</td>
<td>1</td>
<td>6</td>
<td>Male 7 Female 6</td>
</tr>
<tr>
<td>River Valley College</td>
<td>1</td>
<td>8</td>
<td>Male 3 Female 3</td>
</tr>
<tr>
<td>Coastal Secondary College</td>
<td>2</td>
<td>4</td>
<td>Male 3 Female 7</td>
</tr>
<tr>
<td>Alpine Secondary College</td>
<td>1</td>
<td>7</td>
<td>Male 5 Female 6</td>
</tr>
</tbody>
</table>

16.5.3 Data Collection

Data were collected from multiple sources to allow for triangulation of findings (Yin, 2014) and to improve the overall credibility of the study (Tracy, 2010). Qualitative data were gathered during site visits through semi-structured interviews with participants (Gideon & Moskos, 2012). Staff were asked open-ended questions about perceived contributing factors and impediments to STEM education success at the school. Students were interviewed as a
group and asked open-ended questions about their learning experiences and participation in STEM. Group interviews were used as a way of encouraging adolescent participation, despite the inherent risk of conformity amongst participants (Cohen, Manson, & Morrison, 2011). The researcher addressed each question to each participant to mitigate against potential "group think". In most cases, STEM teachers and principals were interviewed individually, however, on two occasions, in pairs, and on a further two occasions, in small groups due to time and availability constraints. Interviews took place in private and varied in length from 20 to 40 minutes. Interviews were recorded and transcribed, and the transcripts were used for analysis. School documents, including annual reports and student subject selection booklets were also collected for analysis. The researcher also toured the school accompanied by a principal or leading teacher, taking field notes and photographs of educational artefacts (for example, displays, resources, and facilities).

### 16.5.4 Analysis

Within an overall practice architecture theoretical framework, an explanation-building approach to analysis was employed for the case analyses (Yin, 2014), where a set of causal links were sought to explain how and why these rural schools had achieved greater than expected STEM success. Qualitative data was thematically analysed one school at a time. Data were coded using both deductive and inductive themes (Braun & Clarke, 2006). Data was first examined for activities associated with student dispositions in STEM. This was done by searching for synonyms and antonyms of the key words identified by Murphy et al. (2018) in their analysis of Australian STEM education strategies, including engage, motivate, aspire, inspired, confidence, curiosity, resilience and mindset. Following this, through iterative engagement with the data coded as impacting on student dispositions at a particular school, inductive themes were identified, a process Braun and Clarke describe as "organic thematic analysis" (Braun & Clarke, 2006, p. 741). The prominent themes in participants explanations of their schools' STEM engagement success are shown in Table 16.3.

<table>
<thead>
<tr>
<th>STEM Practice theme</th>
<th>SPC</th>
<th>RVC</th>
<th>CSC</th>
<th>ASC</th>
</tr>
</thead>
<tbody>
<tr>
<td>High expectations with support</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hands on learning experiences</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Real world learning contexts</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Place-based learning</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Science electives</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Differentiation in Mathematics</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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Finally, cross case synthesis was conducted (Yin, 2014), comparing and contrasting the practices associated with student engagement across the four different schools, and exploring the factors that enabled and constrained these practices at the different sites. This synthesis is presented in Section 16.6.
16.6 Practices Associated with STEM Engagement – A Cross-Case Synthesis

This section synthesises the practices associated with increased student engagement in STEM listed in Table 16.3 across the four schools, and considers their alignment to the theoretical understanding of motivation and emotion in STEM and rural education outlined in Sections 16.2 and 16.3.

16.6.1 High Expectations, Generous Support and Passion

High expectations for students to do their best, backed by generous teacher support from teachers passionate about teaching and their disciplines, was a practice felt to improve student engagement at all four schools, as illustrated by this quote from an RVC student:

> The actual level of enthusiasm and commitment and how much these teachers care here, not even in the higher years, in the lower years as well, how much they actually care about the students and how well they do is awesome... it is one of the reasons why everyone is always doing harder subjects and always pushing themselves because they have teachers there that care and are putting in a lot of time and effort for it.

All four schools had established a culture of high expectation for learning in STEM, either within the school and in some cases beyond. Students said that teachers “push us”, “expect you to do your best”, expect students to “have a go yourself”, and that they “just really want us to succeed”. The expectation of effort and achievement seemed to be a social norm at the schools. Many students made comments like “it’s okay to try hard”, “everyone wants to do well”, “it’s seen as desirable to do well at school here”, and “we want the rest of the class to do well as well”, suggesting that achievement in STEM has attainment value for students at these schools. At SPC parental support was also seen as a motivating factor by several STEM teachers, one who said, “parents always encourage their kids and support them and push them.” However, at RVC and CSC, teachers noted that education was not always highly valued, and that home life, such as work on the farm, sometimes distracted from school engagement.

These high expectations were not seen as focused upon achieving high grades in STEM, but rather on effort and continual improvement, reflecting a mastery goal orientation. An ASC teacher said, “[I]t doesn’t matter where you start, it matters that you grew from where you were to where you are now.” The students felt that expectations were reasonable and achievable, particularly with the level of support teachers offered. An ASC student commented:

> They don’t expect so much that they make it an impossible thing to achieve those goals. But they try and help you along... but not to the point where they’re doing it for you. Just enough to get you to where you need to be.

Students saw the ready and plentiful support offered by their STEM teachers throughout secondary school as motivating. A CSC student commented “The thing that I’ve really loved since Year 7... I’m not the smartest at the top, but I always feel like I’ve got that help in hand. I’m not always behind.” STEM teachers offered help at lunchtimes, after school, and during holidays. RVC and CSC both ran formal after school homework programs attended by students of all ages, with a focus on mathematics. Many teachers shared contact details with
their senior students, and several teachers at RVC made use of Facebook groups to support senior students after school hours. Students also felt that this level of assistance was not common in other schools. An RVC student said, “I think everyone’s aware that not many schools get that sort of treatment… everyone’s free to go… and, yeah I’m sure that makes a hell of a difference to our results. And that’s done from a young age too.” 

Teacher support seemed to impact student self-efficacy, but also seemed to be motivating as it enhanced student-teacher relatedness. A CSC student commented, “You do wanna impress them because you do have that relationship with them and you wanna show that they’re teachings not going to waste.” 

The schools recognised that the scale of the school and the nature of rural communities facilitated offering this level of support in STEM. Small class sizes made offering individualised support more feasible, however this only goes part way to explaining the degree and success of the support offered. The quality of teacher-student relationships, and in some cases teacher-family relationships was frequently presented as the motivating force behind the support offered and the reason for its uptake and success. STEM teachers across the schools spoke about how their involvement in local sporting bodies and community groups contributed to their relationships with their students. Others felt their role as a parent at the school had been important. One SPC teacher explained her willingness to work hard for her students, saying, “These are kids of people I know, I’ve had my kids come through, and you just want the best for them.” An SPC student reflected, “I think in rural areas… we’re seeing our teachers all the time and not just in school but outside school… so you’ve got a bit more of a personal relationship with them than just that work sort of relationship.” 

A further factor cited as contributing to student engagement in STEM at the schools, and present in participant discussion of expectations and support, was the obvious passion of the STEM teachers for their discipline and their teaching. The SPC principal said, “I think that’s some strong passionate teachers in those areas and they choose accordingly.” Many teachers across the schools believed teacher enthusiasm increased student interest in STEM, commenting, “teachers are enthusiastic, and that wears off on kids” and “teachers are passionate which inspires students in the area”. Students said that their STEM teachers were obviously interested and excited about what they were teaching and that “has a trickle-down effect on kids”. Student comments such as “makes you excited to learn” and “you’re just entertained by that” suggests that the teacher’s passion fostered positive emotions towards STEM. Students felt that teacher enthusiasm also motivated reluctant STEM learners. A RVC student said, “She was just really enthusiastic, just loved maths and, well, even if not everyone did, they learnt a hell of a lot. She just kept everyone going.” A student from CSC who self-identified as a reluctant STEM learner said of her STEM teachers, “They’re actually having a good time and smiling and asking questions and being all enthusiastic about it, then like ‘oh that’s cool’.”

16.6.2 Hands-On, Real-World, and Place-Based STEM Learning

Hands-on activities, real-world learning, and place-based learning were believed by participants to contribute to student STEM engagement. Hands-on learning involves students learning by doing, through using equipment and concrete materials (Flick, 1993). Real-world learning involves learning applied to contexts relevant to students’ current lives, futures, or
wider world issues. Place-based learning is a sub-set of real-world learning, involving
learning in and/or applied to local areas and contexts, and often includes hands-on activities
(Centre for Education Statistics and Evaluation, 2013).

Hands-on activities were understood to contribute to the interest-value of tasks, as
well as fostering positive academic emotions. Teachers described an extensive range of
hands-on activities across the study, including building spaghetti bridges, constructing and
racing cars, launching rockets, and Barbie™ bungee jumping, variously asserting that these
activities “get[s] them interested”, “gets them in”, and were “cool” and “fun”. The CSC
mathematics leader felt that without the use of “equipment and hands on stuff…you’re going
to lose them straight away.” Students across the schools nominated hands-on activities as
increasing interest in STEM, with one CSC student suggesting the lack of hands-on
opportunities in other subjects rendered them “really bland and kind of boring.” A CSC
student suggested that hands-on activities are particularly important for rural students, “Well
most of us are from farms and stuff and we are hands on when we’re out there helping your
dad or something… so when we come to school we want it to be hands on again.”

Real-world learning occurred across all schools and was seen to increase the
perceived utility value of STEM. In mathematics, many teachers spoke about using real
world contexts, including finance and sport, for problem solving. Mathematics teachers as
SPC worked systematically to connect learning to real world contexts, writing on the board at
the beginning of the lesson the real world reason for the focus of the lesson. Science and
technology classes often simulated real world contexts; for example, a mock-up body farm in
forensic science at RVC, and designing and building model Formula One cars at SPC.
Students commented that real world learning is motivating as it shows that “there’s a real-life
connection to it” and that they “could probably use this in life”.

ASC’s science elective program, which extends from years 8 to 10, seemed to impact
student engagement in STEM, through improving task value, autonomy, and academic
emotions. This program included units with obvious real world connection such as “Small
engines”, “Medical science”, “Robotics”, “Animal science” and “Forensics and psychology”.
Students commented that the electives were “really fun” and effective at “drawing you in”.
Enrollment numbers also suggest that the science electives were particularly engaging, with
science electives attracting more student preferences than other subjects. Staff felt that the
students valued the opportunity to choose their science subjects and that the hands on and real
world nature of the subjects resulted in higher enrollments in VCE sciences. It is worth noting
that science was also offered as an elective in Years 9 and 10 to the 2014-2016 cohort at both
CSC and RVC, though participants at these schools did not highlight this element as
contribute to STEM engagement.

Place-based STEM learning was viewed as a key practice at RVC and CSC, but was
also present to some degree at the other two sites. It was seen as contributing to engagement
through improved task value, as well as by enhancing relatedness, autonomy and positive
emotions. Place-based learning experiences included students constructing bun targets to
minimise school littering at RVC, raising cattle as part of the Cows Create Careers program
at RVC and SPC, construction of waterproof storage boxes for campsites near CSC, and
public lighting sculpture installations near ASC. Common to many of these experiences was
the opportunity for students to connect with other students, adults and the wider community.
For example, RVC secondary students frequently shared their STEM projects with students
in the primary school, and ASC worked students with local experts in water management and
power generation. Place-based projects typically supported student autonomy, with students contributing significantly to the planning and implementation of projects. For example, some CSC students campaigned successfully for a plastic bag free retail sector, while others were involved in habitat regeneration at a local creek.

Several staff at RVC and CSC felt that place-based learning particularly suited their rural students and that there were rich resources in rural areas for this learning approach in STEM. A CSC principal commented “I think it’s something that the kids are interested in, the outdoors. And they get more access to that here in the country.” Students also valued the use of rural contexts for STEM learning. One CSC student, describing local ecosystem investigations, said, “I think that was pretty cool, just knowing that you can do that kind of test in local environments.”

16.6.3 Differentiation and Managing Academic Emotions in Mathematics

There was an emphasis at three of the four schools on mathematics education practices that tailored learning to individual students and built student confidence in mathematics. RVC, CSC and SPC all used differentiated instruction in their mathematics classes, albeit in different ways. Differentiated instruction involves a cycle of pretesting, goal setting, individualised instruction and practice, and post-testing (Prast, Van de Wetering-Bergsma, Kroesbergen, & Van Luit, 2015). At CSC, the delivery of this program was largely paper-based, with instructional programs kept in colour-coded folders, and students using worksheets and text-books. After a topic pre-test, students are allocated a colour-coded task sheet from which they select and complete various tasks, which they self-assess. Each task is assigned a star value and students need to earn a certain number of stars before they are ready for the post-test. At RVC and SPC the programs are managed through an online learning management system, with students using spreadsheets to track their learning and accessing some instruction and practice materials online. SPC publicly displayed student progress on a large chart in the classroom, and gave regular mathematics awards at assemblies for effort and improvement. It was noted that some students at both RVC and SPC were also accessing the online component of these programs from home.

This approach to mathematics delivery was seen as improving student self-efficacy and autonomy, while minimising student boredom and disengagement. A CSC student commented that through the program, “my confidence boosted up and then my marks went up because… I wasn’t thinking in my head, I’m terrible at this, I don’t want to do it.” The numeracy leader at SPC said that, through the program, students are “building that independence and actually working towards achieving their goals and learning more and more.” An ASC teacher felt that student autonomy was a key aspect of the approach, commenting, “It’s the kids’ data. They need to own it… Same with learning goals.” Students across the schools said differentiated instruction meant they didn’t “get stuck” or “keep going over the same sort of stuff” and that they are “not getting bored.” The mathematics teacher at CSC felt that differentiated instruction kept all students engaged, commenting, “There’s never gonna be a time that you need to go off with the fairies or muck around because it’s always gonna be something that you can do.”

In addition to the differentiated structure of mathematics education, there was also strong awareness of the importance of managing students’ academic emotions in mathematics. The numeracy leader at RVC commented that maths is “the worst subject as far
as damaging kids. It’s really bad” and a teacher from ASC said, “If a kid thinks that they’re dumb at maths, forget about it, that’s it.” Efforts were made at each school to ensure that teacher-student interactions contributed positively to student engagement in mathematics. An RVC teacher said “It’s not, ‘oh you got the right answer’ but ‘look how much you’ve improved by’, [or] ‘I know that you have difficulty in this’ but ‘look how I can help you’.” A CSC student reflected on her experience, “I got to Year 7 and my teacher was fabulous. I’m like, look I’m not confident in Maths, I don’t think I’m very good and she’s like, no you can do it, you’re fine… we’re gonna change your mindset and get you into it.”

16.6.4 Raising the Profile of STEM through Enrichment Programs, Careers Education and Technical Training

In one form or another, STEM seemed to have a high profile at each school. An ASC student commented, “I don’t know what it is specifically, but there seems to be a large STEM culture in this school.” A RSC student felt “We’re quite a strong science based school, we’re in an ag. community and science is probably something that most of us probably look at”. SPC is known for its mathematics and technology, with one teacher saying, “I just think the students, for whatever reason, seem to be able to pick up maths or enjoy maths or … feel that maths is something that once they get into it they can use it for lots of other things.” At CSC the STEM teachers have a strong reputation within the community, “We’re sort of well-known around the community and we’re strong, respected.”

While the classroom programs contribute to the profile of STEM, each school employs additional activities that are seen as raising the profile of STEM and improving student engagement. ASC STEM teachers organise extensive extra-curricular STEM activities drawing on grants and support programs to allow their isolated students to participate in these enrichment opportunities. Students found these programs engaging, a typical comment being, “They definitely try and push more experiences and opportunities on us, which I think that’s why it’s everyone is quite passionate about it.” At RVC, senior classes regularly share their STEM learning with junior students, and students organise and run well attended STEM events for students and their families. RVC also runs other high profile activities that are STEM related, such as emergency service days, and firefighting training. CSC STEM teachers felt that their strong promotion of STEM to parents and students at information nights leads to increased enrolments. CSC also felt its outdoor education and community service programs also contributed to the profile of STEM at the school. SPC teachers strongly promoted mathematics education, through regular contributions to the school newsletter, awards at fortnightly assemblies, and occasional whole school mathematics days. SPC teachers also felt that their extensive STEM related technical training programs in careers like building and construction, agriculture, animal science, and allied health, contributed to the STEM profile at the school.

The schools leveraged strong relationships with the local community to run many of these programs. Community groups like Rotary and Lions support the STEM enrichment experiences at ASC, RVC and CSC collaborate with local services and volunteers to run many of their programs. The VET programs at SPC are dependent on the school’s collaboration with local employers and nearby schools.

Though not strictly a STEM education practice, three schools felt their extensive careers education programs contributed to the profile of STEM and their high enrolments in
senior STEM subjects. SPC, RVC and ASC all have careers classes, commencing in years 7, 8 and 9 respectively, and continuing into the senior years. There are also annual career information evenings and individual counselling for senior students. The SPC principal commented, “That really, I think, supports students when they’re making choices for subjects entering into VCE; there’s great knowledge there and recommendation regarding the need for your maths subjects for example.” Many teachers referenced careers education at their schools as a factor in explaining high VCE STEM participation, saying the programs offer students a “really clear structure” and make students “comfortable with their future career choices.” Students also felt that the careers program encouraged the choice of senior STEM. One ASC student said, “I think they kind of know what you want to head, like what direction you want to go in career wise, so they can help you aim for those subjects.” Another student noted that the programs encouraged students to consider growing STEM related industries like “more aged care and more health and medicine areas.”

16.7 Discussion and Conclusion

Each of the four rural schools engaged in a complex array of practices believed by the participants to contribute to the above-expected STEM success of their schools, particularly by maximising student engagement. The participants’ responses suggest that these practices motivated students to engage with STEM learning in various ways, as summarised in Table 16.4. As can be seen in this table, practices believed to contribute to the schools’ STEM success were most often described as impacting on task value, aligning with the work of Goo et al. (2015). These practices were commonly described as highlighting the utility value of STEM, involving interesting activities, and contributing to STEM achievement being viewed as desirable. Another motivational construct commonly viewed as influenced by the school’s practices was academic emotions, in line with the findings of Simon et al. (2015).

Some practices were felt to impact on motivation through a range of mechanisms. Maintaining high expectations with generous support was viewed by each school as a key contributor to STEM success. This practice was described as impacting student motivation through fostering self-efficacy, attainment value, relatedness, mastery-goal orientation, and positive feelings towards STEM. This finding builds upon those of Wang and Holcombe (2010) and Hardrè et al. (2009). However, where these authors emphasised teacher support and teacher-student relationships, the schools in this study coupled these to holding high expectations for STEM learning. Further, the passion STEM teachers had for their subjects was seen as facilitating this practice.

Each school variously acknowledged the contribution of hands-on learning, using real world learning contexts, or place-based learning to their performance in STEM education. Of these, place-based learning seemed to impact the broadest range of motivational constructs, providing interest and utility value, supporting autonomy, using student connections to their locality, and fostering positive emotions. This finding adds support to recommendations for place-based learning to foster rural student engagement (Centre for Education Statistics and Evaluation, 2013).
Table 16.4 Practice themes believed to contribute to student engagement in STEM by motivational construct

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<thead>
<tr>
<th>STEM Practice theme</th>
<th>Self-concept/self-efficacy</th>
<th>Task value</th>
<th>Autonomy</th>
<th>Relatedness</th>
<th>Mindset</th>
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There was a particular focus on promoting positive mathematics self-concept in three of the schools. Well-resourced and highly differentiated mathematics programs were felt to build student self-efficacy, and provide student autonomy. The structure of the mathematics program was carefully supported by teachers who attended to the emotional welfare of their students, encouraging effort and building student confidence with appropriate support. These rural schools did not follow the trends noted by Hardré (2011) in rural schools of low student self-concept in maths and less supportive mathematics teachers. Interestingly, however, the case schools did not place the same emphasis on self-concept in science and technology subjects.

There were also a range of autonomy supporting mechanisms used by the schools, including science electives, self-directed mathematics learning, and several of the place-based learning programs. While it has been theorised that autonomy-supportive practices are motivating (Camach et al., 2017), participants in the case schools only rarely spoke about student autonomy as contributing to student engagement in STEM.

Some other aspects of engagement theory were relatively absent in participants' accounts. When discussing expectations, support and managing academic emotions, there was a focus on improvement across the sites, however only STEM teachers at RVC had adopted an explicit growth mindset approach. There was some evidence of students being involved in goal setting, particularly associated with the differentiated mathematics program, though these goals seemed associated with meeting benchmarks and targets rather than being true mastery goals.

Some of the practices associated with STEM engagement were facilitated by the rural location of the schools. The small school size and closeness of the rural community was seen as contributing to STEM teacher-student relatedness, and to teachers' abilities to understand...
and address the academic and emotional needs of each of their students. The schools made extensive use of the local resources and community networks to facilitate real world and place-based learning, as well as to support their careers and technical training programs. This adds weight to scholarly arguments that effective rural schools capitalise on the characteristics of their local community (e.g. Haddré et al., 2008). For other practices associated with STEM engagement, the rural location was an impediment, with schools noting difficulties in funding and accessing STEM enrichment opportunities.

This multi-case study identifies numerous practices associated with STEM engagement at four relatively high STEM performing rural schools, including: holding high expectations with generous support, place-based learning, STEM enrichment opportunities, and differentiated mathematics programs. While these practices are not peculiar to rural schools, the schools' rural nature, including their small communities, close relationships, and local resources, were seen as facilitating many of these practices. However, this study cannot conclude that any one practice, or set of practices, led to high STEM engagement at these schools. Given this, it does not describe a generalisable approach for implementation by other schools, but rather provides transferable insights into STEM education practices that may build student engagement and achievement in STEM, particularly in small rural schools. Further research into student engagement practices in other high STEM-performing rural schools, along with comparison with practices at less STEM successful rural schools, would build on the findings of this study, offering more direction to rural schools and policy makers hoping to improve the engagement of rural students with STEM.

References


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