THE DEVELOPMENT AND ASSESSMENT OF STEM SKILLS IN AUSTRALIAN HIGH SCHOOLS

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Declaration

This thesis contains no material that has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge and belief it contains no material previously published or written by another person except where reference is made in the text.

Jennifer M. Colley

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To Grandma,

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Love and God bless,

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xxx

Abstract

This thesis examines the development and assessment of science, technology, engineering and mathematics (STEM) skills within the context of Australian high schools. This is with a view to establishing what Australian employees consider STEM skills to be, the extent to which they can be developed within high schools, and whether the predominant means of their assessment are valid.

While the phrase ‘STEM skills’ is often used by all manner of stakeholders, very few articulate which specific skills they mean under this umbrella term. A survey of the literature, with a focus on the STEM skills desired by employers, was used to propose five domains of skills that are suitable for development within a high school context. These are: literacy; disciplinary; higher order thinking; interpersonal; and intrapersonal skills. Each of these are described in terms of the specific types of skills that fit within these domains. Year 7-10 STEM teachers from across Australia were surveyed regarding what they associate with the phrase STEM skills. It was found that there were many overlaps between skills identified from the literature and by teachers, but both sources included, and omitted, some skills the other did not.

The components of the Australian Curriculum pertaining to STEM in Years 7-10, the final years of compulsory STEM education, were examined to see what skills were articulated within the curriculum. These skills were compared with the skills identified from the literature. It was identified that the Technologies curriculum, Design and Technologies in particular, facilitates the development of the broadest range of skills and presents opportunities to engage with integrated STEM education. Teachers were also asked about their familiarity with aspects of the curriculum and the degree of support they felt it provided in developing STEM skills. A range of improvements would help to better support teachers to enable their students to develop the STEM skills Australian employers want.

Two international standardised tests, the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) that are typically used to argue that Australia is falling behind in STEM were analysed. It was found that they both place a large focus on knowledge and that the higher order thinking skills they seek to assess can often only be effectively demonstrated if the student has the required background knowledge. Neither assess many of the STEM skills identified from the literature or by teachers and thus are proposed to be ineffective metrics, in and of themselves, for determining the level of Australian students’ STEM skills.

The thesis concludes with recommendations and limitations as well as identification of future areas of research by way of suggesting how teachers could be better supported to develop the STEM skills in their students that Australia’s employers want in their employees.

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Abbreviations and Acronyms

AA	Asia and Australia's Engagement with Asia
ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
ACARA	Australian Curriculum, Assessment and Reporting Authority
ACER	Australian Council for Educational Research
ACOLA	Australian Council of Learned Academies
AITSL	Australian Institute for Teaching and School Leadership
ASbA	Australian School-based Apprenticeship
ATAR	Australian Tertiary Admission Rank
ATI	Aboriginal and Torres Strait Islander Histories and Cultures
ATWD	Australian Teacher Workforce Data strategy
C&C	Critical and Creative Thinking
DAE	Deloitte Access Economics
EFT	Equivalent Full Time
EU	Ethical Understanding
EU11	European Union in the case of EU11
ICT	Information and Communication Technology Capability
IEA	The International Association for the Evaluation of Educational Achievement
IU	Intercultural Understanding
K-12	Kindergarten to Year 12, the years of schooling from age 5-18
L	Literacy
N	Numeracy
NAP	National Assessment Program
NAP-ICTL	National Assessment Program ICT Literacy
NAPLAN	National Assessment Program Literacy and Numeracy
NAP-SL	National Assessment Program Science Literacy
NCVER	National Centre for Vocational Education Research
NRC	National Research Council
NSF	National Science Foundation
NSW	New South Wales
NT	Northern Territory
O*NET	Occupational Informational Network
OCS	Office of the Chief Scientist
OECD	Organisation for Economic Co-operation and Development
PIRLS	Progress in International Reading Literacy Study

PISA	Programme for International Student Assessment
P&SC	Personal and Social Capability
QLD	Queensland
S	Sustainability
SA	South Australia
SMET	Science, Mathematics, Engineering and Technology
STEM	Science, Technology, Engineering and Mathematics
STEAM	Science, Technology, Engineering, Arts and Mathematics
STEMM	Science, Technology, Engineering, Mathematics and Medicine
STEMSS	Science, Technology, Engineering, Mathematics and Social Studies
STREAM	Science, Technology, Reading, Engineering, Arts and Mathematics
TALIS	Teaching and Learning International Survey
TAS	Tasmania
TIMSS	Trends in International Mathematics and Science Study
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organisation
US	United States
VET	Vocational Education and Training
VIC	Victoria
WA	Western Australia

Chapter 1 – Introduction

Background

Education makes regular adjustments in line with national and international political, social and economic developments (Blackley & Howell, 2015). At present within educational circles, both in Australia and beyond, it is difficult to avoid encounters with the acronym 'STEM'. It is agreed that the four letters stand for Science, Technology, Engineering and Mathematics. However, its meaning is far more complex, highly contextualised, and subject to vast differences in interpretation (Timms, Moyle, Weldon, & Mitchell, 2018). This is largely due to the number of stakeholders who have a vested interest in STEM, such as government officials, businesses and industry, universities, educational researchers, teachers, parents and students (Breiner, Harkness, Johnson, & Koehler, 2012).

> Australia's productivity and competitiveness is under immense pressure. A key way to meet the emerging challenge of developing an economy for the 21st century is to grow our national skills base – particularly the Science, Technology, Engineering and Mathematics (STEM) skills of our school leavers. Our relative decline of STEM skills is holding back our national economy and causing real frustration for employers (Australian Industry Group, 2013, p. i).

This quote by the Australian Industry Group expresses a sentiment which has been frequently articulated by the Australian Government, in particular through the Office of the Chief Scientist (OCS), and a wide range of STEM stakeholders. Three things within this quote ought to be noted. First, the notion of the connection between STEM and international competitiveness (Australian Industry Group, 2013). In an OCS (2014b) paper it was noted that Australia was the only country within the Organisation for Economic Co-operation and Development (OECD) which did not have a national strategy on STEM.[1] The lack of such a strategy was deemed by the OCS (2014b) to be seriously hampering Australia's competitiveness in what is an increasingly scientific and technological world. This connection between STEM, productivity and competitiveness is a sentiment held by many nations, and is a large part of the rationale for the worldwide focus on STEM (Marginson, Tytler, Freeman, & Roberts, 2013).

Second, it is claimed that Australia has experienced a relative decline in STEM skills (Australian Industry Group, 2013). This is a claim which is relatively difficult to confirm or deny in that STEM skills, whilst often discussed, are very rarely elucidated in any detail. Within an international schooling context, the OCS (2014a) used the Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) to benchmark Australian students' performance against other nations. There is evidence that the performance of Australian students relative to their international peers has been decline in these two tests (S. Thomson, De Bortoli, & Underwood, 2016; S. Thomson, Wernert, O'Grady, & Rodrigues,

[1] A National STEM Strategy for 2016-2026 was released by the Education Council (2015).

2016). However, the extent to which these tests measure STEM skills needs to be established if they are to be used to benchmark Australian students' STEM skills specifically.

Finally, this decline in skills has been claimed to be causing frustration for employers (Australian Industry Group, 2013). One of the key factors in the worldwide focus on STEM within education is the STEM workforce shortage argument. This is characterised by employers in STEM fields having difficulty finding suitably skilled employees. Yet, at the same time, STEM graduates in Australia are currently having difficulty gaining employment (Norton, 2016), leading to something of a paradox that is present in other countries also (Harris, 2014; Kramer, Tallant, Goldberger, & Lebus, 2015). The STEM workforce issue is a complicated one and lies largely beyond the scope of this thesis. Nevertheless, what does appear evident is that it is beneficial for a greater number of people within the workforce to have a higher skill level and a broader skill set.

The statement from the Australian Industry Group (2013) which opened this chapter highlighted the skill level of school leavers. The responsibility for the early cultivation of these skills is firmly on the shoulders of curriculum developers and teachers. Therefore the focus of this study has been placed on Years 7-10, the final compulsory years of STEM subjects in Australian schools (Australian Curriculum, Assessment and Reporting Authority (ACARA), 2014c).

Statement of the Problem

The Australian Industry Group (2013) quote on the previous page suggests that improving the STEM skills of Australian school leavers is a key way in which the national skills base can be expanded. This puts responsibility on the education system, secondary school teachers in particular, to develop their students' STEM skills. A focus on the development of skills within a high school environment is logical as that is where the next generation of workers is to be found. However, despite the phrase 'STEM skills' being frequently used in reports on STEM worldwide, very few stipulate the skills that are specifically desired. For example, an examination of a number of OCS (Baranyai et al., 2016; OCS, 2012; 2013a, 2014a, 2014b) and Australian Industry Group reports (2013, 2015) only yielded vague references to literacy, technical and scientific skills, quantitative skills, critical thinking and creativity. It is far more typical to use the phrase 'STEM skills' with no qualifier whatsoever. If teachers are to have a chance of cultivating the desired skills in their students, it is necessary to articulate clearly the skills meant by the phrase.

It is also necessary to consider the extent to which Australian teachers are supported to develop these skills in their students. This requires a consideration of the extent to which the Australian Curriculum facilitates the development of these skills as this curriculum is enacted Australia-wide (ACARA, 2014c). Finally, in implementing any educational change, evidence must be able to be collected to demonstrate that the approach is working, in this case, that students' STEM skill levels are increasing. Thus, it is necessary to identify whether the methods currently used to monitor progress, namely PISA and TIMSS, are appropriate metrics for assessing Australian students' performance in STEM.

Research Questions

The key question that emerges from the literature in response to this problem is "How are Australian teachers to develop and assess the STEM skills their students will require to succeed in the workforce of today and tomorrow?"

By way of addressing this overarching question, three research questions will be investigated:

- Research Question 1 – What are STEM skills?
  - Research Question 1a – What are STEM skills according to the literature?
  - Research Question 1b – What are STEM skills according to Australian Year 7-10 STEM teachers?
  - Research Question 1c - How do the perspectives on STEM from the literature and from Australian teachers compare?
- Research Question 2 – To what extent does the Australian Curriculum support the development of STEM skills?
  - Research Question 2a – What skills are made explicit in the general capabilities, cross curriculum priorities, and STEM learning areas of the Australian Curriculum?
  - Research Question 2b – to what extent to Australian Year 7-10 STEM teachers feel the Australian Curriculum supports them in developing STEM skills in the students?
- Research Question 3 – To what extent do PISA and TIMSS assess STEM skills?

These questions were addressed through four interrelated aspects of this study, as outlined in the following section.

Overview of Method

Research Question 1 – What are STEM skills?

Research Question 1a – What are STEM skills according to the literature? The conventional literature as well as relevant government and industry reports were examined to develop a conclusion regarding the STEM skills desired by employers that can be developed within a high school context. The skills identified from the literature were classified into five domains with a non-exhaustive list of skills that might be included within each domain.

Research Question 1b – What are STEM skills according to Australian Year 7-10 STEM teachers? A survey of Australian Year 7-10 STEM teachers from all Australian states and territories and all secondary education sectors was conducted online via SurveyMonkey. It may be found in Appendix A. The survey was disseminated via social networking sites such as Facebook and Twitter as well as directly to schools to be shared with their STEM teachers. The survey asked teachers about their familiarity with the phrase 'STEM skills' and to list skills they associate with the phrase.

Research Question 1c – How do the perspectives on STEM skills from the literature and from Australian Year 7-10 STEM teachers compare? The domains and relevant skills identified from the literature were compared with those elicited from teachers so that the extent to which these two perspectives align could be ascertained.

Research Question 2 – To what extent does the Australian Curriculum support the development of STEM skills?

Research Question 2a – What skills are made explicit in the general capabilities, cross-curriculum priorities and STEM learning areas of the Australian Curriculum? The general capabilities and cross-curriculum priorities, two overarching aspects of the Australian Curriculum designed to be addressed by all learning areas, were examined to determine the skills inherent within them. The Year 7-10 curricula of the STEM learning areas – Mathematics, Science, and the Technologies (Design and Technologies and Digital Technologies within the Australian Curriculum) – were analysed in full for references to skills to see which skills were explicitly outlined within the curriculum.

Research Question 2b – To what extent do Australian Year 7-10 STEM teachers feel the Australian Curriculum supports them in developing STEM skills in their students? A section of the survey described under Research Question 1b was used to determine the level of familiarity teachers had with each aspect of the Australian Curriculum as well as how supportive they found the Australian Curriculum to be in the development of STEM skills.

Research Question 3 – To what extent do PISA and TIMSS assess STEM skills?

Given results from PISA and TIMSS are generally used to compare how different countries are performing in STEM (Marginson et al., 2013), it is necessary to determine which skills these two tests assess. The skills assessed must then be compared with the STEM skills identified from the literature and relevant government reports to see the extent to which they overlap. The framework documents from the first iteration of PISA (2000) and TIMSS (1999) through to the most recent cycle for which complete data and analysis for both tests was available (2015) were analysed. For PISA, reading literacy and financial literacy were omitted as they are not directly connected to STEM. The mathematical literacy, scientific literacy and problem solving frameworks for each test were analysed. For TIMSS, both mathematics and science (the only domains of this test) were examined.

Significance

This study seeks to determine the skills required for today's students to make effective contributions to tomorrow's workforce. At present, there is a strong focus upon the STEM workforce internationally (Marginson et al., 2013) and yet STEM education is still in its relative infancy (Bybee, 2016). The findings of this study therefore have the potential to be of significance to stakeholders in STEM ranging from Year 7-10 STEM teachers through to the STEM workforce.

The focus on the phrase 'STEM skills' and what is meant by it is of significance to anyone working within, as well as beyond, the STEM sector as it is a term that is used frequently and yet lacks a universally agreed upon definition. Clarity regarding what may be meant by this phrase is of benefit to all stakeholders. It is of particular benefit to teachers of STEM disciplines who are charged with developing this undefined set of skills.

The examination of the Australian Curriculum and participation of Australian teachers helps to frame what is an international issue within an Australian context. The Australian Curriculum was introduced less than a decade ago and is up for a second review, commencing with mathematics and science (Karp, 2019). Consideration of how well the STEM learning areas facilitate the development of STEM skills is of benefit for reviewers of the curriculum, ACARA, Ministers for Education and all those who interact the STEM disciplines within Australian schools including teachers, students and parents. Additionally, gaining an understanding of the extent to which teachers are familiar with various aspects of the Australian Curriculum will provide some insight into the extent to which each aspect of the curriculum is being enacted. This will be of benefit to those involved in the curriculum review and implementation.

The focus of the second review of the Australian Curriculum is commencing with mathematics and science in response to Australian students' continuing negative trend in standardised testing when compared with their international peers (Karp, 2019). This is yet another example of the reliance on PISA and TIMSS results as an indicator of Australian students' performance in mathematics and science. An examination of what these two tests assess will enable stakeholders to be more cognisant of what conclusions can be reliably drawn from the data, and thus applied to curriculum and schooling.

Collectively, this work has implications for anyone working within the STEM sector. The focus of the study is placed on Years 7-10 because this is an important section of the STEM pipeline

(Office of the Chief Scientist, 2014a). This is because it is the first stage at which many students may be lost because it is the last time these subjects are compulsory. However, the findings also have implications for people in the university and vocational education sectors, as well as STEM employers.

Limitations

The key limitation that is foreseen is the sample size of the survey and how effectively it will represent the Australian teaching population. Methods including involvement of students and visiting schools or interviewing teachers were not used as the challenges inherent in such methods, especially working with children, were insufficient to warrant pursuing these lines of enquiry. Instead, an online survey that teachers could complete at any time seemed to be a more likely avenue to obtain results appropriate to the nature of the research questions. However, teachers are notoriously busy people and there is no good time of year to ask a teacher to do anything more than they are already doing. The choice to make it a nationwide sample which went across all three sectors was primarily chosen to help increase the sample size. If sufficient responses from each state and territory and/or each sector were obtained, then this would allow for additional analysis of any geographical or sectoral differences, and if not they would be treated as one population.

Information that could be freely obtained, such as the Australian Curriculum and assessment frameworks of PISA and TIMSS, made analysis of those components of the study quite straight forward and so no substantial limitations were foreseen.

Structure of the Thesis

Chapter 2 explores the origins of STEM and describes what STEM means, beyond being an acronym for Science, Technology, Engineering and Mathematics. The concept of STEM literacy is also explored before a transition to a focus on the nature of STEM education within Australia. Chapter 3 examines the key arguments for the focus on STEM. First, that it is beneficial for all citizens to be STEM literate and thus receive at least a basic education in STEM. Second, that the STEM sector is growing and people with STEM skills are able to move across sectors with relative ease due to their skill set. Consideration of the potential issues pertaining to the strong focus currently being placed on STEM within education are also explored.

Chapter 4 outlines the methods and analyses used to address the three broad research questions. Chapters 5 to 7 present an integrated results and discussion for each research question. Chapter 5 examines the portrayal of STEM skills in the literature and the development of a framework of STEM skills suitable for development within high schools. This is then compared with teacher perspectives on STEM skills. In Chapter 6, skills within the Australian Curriculum are identified and compared with those listed in the framework of Chapter 5. Australian teachers' familiarity with various aspects of the curriculum are also discussed in Chapter 6. Chapter 7 is comprised of an evaluation of the skills assessed within PISA and TIMSS as described by their respective framework documents.

Finally, Chapter 8 details the conclusions drawn from Chapters 5 to 7 and provides an answer to each of the research questions by way of addressing the overall question of the skills needed by Australian high school students to succeed in today's workforce. Recommendations are made, limitations identified, and possible avenues for future research are noted.

Chapter 2 – What is STEM? What is STEM Education and what does it look like in Australia?

Introduction

As STEM education research remains in its infancy, the review of the literature presented in Chapters 2 and 3 draws not just on scholarly literature but also reports from industry and government and these three sources will be collectively referred to as the literature. This chapter commences with an examination of the history of the STEM movement, both generally and within education specifically, before transitioning into a discussion of the notion of STEM literacy. The chapter concludes with an overview of Australia's current approach towards STEM within an educational context.

The History of STEM Education

While science and mathematics have been a focus within school curricula for over a hundred years, the first inclusion of engineering and technology within high school education occurred in the 1990s. It was at this time that national standards for science education from Kindergarten to Year 12 were composed by the National Science Foundation (NSF) and other agencies (Angier, 2010) in the United States (US). At this time, the four areas of education – science, mathematics, engineering and technology – were abbreviated to SMET. The phrase STEM subsequently arose from the NSF in the US as a replacement for SMET, which was deemed to have too vulgar a connotation (Breiner et al., 2012; Sanders, 2009). While the four letters stand for the same disciplines, the original order arguably more accurately reflects their relative focus, particularly within high school education, where science and mathematics typically overshadow engineering and technology. It is widely accepted that STEM, as opposed to SMET, was first used by Judith Ramaley, former Director of the NSF's Education and Human-Resources Division, in 2001. She used it when in referring to learning in the context of solving real-world problems within the science, technology, engineering and mathematics curricula. Since this time the acronym STEM has been used to an increasing degree across all levels of government, scientific communities and a range of industries. It has likewise been used in formal and informal education from pre-school to the tertiary sector (Breiner et al., 2012; Daugherty, 2013; Murphy, MacDonald, Danaia, & Wang, 2019).

The move from SMET to STEM reduced the vulgarity of the term whilst maintaining an easily pronounced acronym, indeed it is an English word. However, this has created another problem with respect to people not knowing what is meant by 'STEM' (Breiner et al., 2012). In a poll of 5000 people on 'STEM Education' conducted by the Entertainment Industries Council, 86% of people did not understand the term, with it being confused with stem cells, branches, leaves and broccoli stems" (Angier, 2010). This demonstrates that there is a serious branding issue, particularly outside of the

STEM field, arising from the utilisation of an arguably too familiar a word for what is, in many cases, an unfamiliar concept.

It is not just the general public who do not have a clear understanding of what is meant by STEM. The Australian Industry Group (2017) conducted a project to strengthen the relationship between schools and industry within a STEM context. They found that

> there continued to be some confusion among teachers about what exactly is meant by the acronym STEM. The primary focus seemed to be on science and technology and mathematics to a lesser extent. Some see the acronym as a descriptor of jobs rather than skills sets (p. 12).

Whilst these teachers were at least aware of the disciplines to which STEM refers, with the possible exception of engineering, the teachers did not see STEM as something pertaining to them. It was to do with jobs, not school subjects and the skills which may be developed within them. It is perhaps of little wonder, therefore, that school leavers' STEM skill levels are found to be lacking (Australian Industry Group, 2013).

Bybee (2016) argues that, even without a clear meaning, the acronym STEM can still be of use at a policy level where it can be taken to mean whatever will be of greatest political value. However, he also indicates that the process of designing programs of learning for students and associated best practice teaching and learning is made difficult due to the lack of consensus regarding what STEM education, or indeed STEM itself, means beyond the four disciplines. Any activity which falls into one or more of the STEM disciplines is commonly tagged as being related to STEM, even if it is in fact focused on a narrow sub-branch such as coding, or conducting a scientific experiment (Holmlund, Lesseig, & Slavit, 2018). Around the world there are STEM centres, STEM programs and STEM courses aplenty, yet with no clarity regarding what STEM means in each of these contexts (Bybee, 2016). STEM could be argued to be the latest buzzword in education. Despite the lack of a clear definition, a focus on STEM education within a school suggests that it is at the forefront of education (A. Smith, 2018).

Sanders (2009) highlighted an important distinction between STEM and STEM Education, indicating that the former is a reference to fields in which people work while the latter pertains to the education of students in those fields. However, there are also misconceptions around the 'T' in STEM, with some thinking it means information technology only, as opposed to a broader focus which includes areas such as design technology (Sanders, 2009). This is compounded by the fact that, within education, technology is generally taken to mean teacher and/or student use of various technologies in their teaching and learning as opposed to the discipline of technology (Bybee, 2016).

Change is hard to effect within education, with teachers commonly continuing to teach in much the same manner, despite changes to the curriculum or the latest development in pedagogy (Bybee, 2016). Thus, "When most people use the term *STEM,* they mean whatever discipline they meant in the past. So *STEM* is usually interpreted to mean science or math. Seldom does it refer to technology or engineering" (Bybee, 2016, p. 2, emphasis in original). This is exacerbated by the fact that there is no engineering subject per se within the Australian curriculum, though it is arguably inherent within Design and Technologies curriculum (ACARA, 2016). Engineering has traditionally been within the purview of tertiary rather than secondary education, which further adds to the difficulties in effective implementation of technology and engineering education within a secondary setting (Holmlund et al., 2018).

As a result of these issues, STEM education is often enacted as S.T.E.M, with the full-stops signifying a siloing of the subjects, or even more commonly as S.t.e.M – siloed with a relative lack of emphasis on technology or engineering (Blackley & Howell, 2015). This is problematic in that not only is STEM in the real-world integrated rather than siloed, there is also typically a larger focus on technology and engineering in the workforce (Redman, 2017). Thus, there is a disconnect between the school and workforce realities of STEM in terms of the relative contributions of the disciplines, let alone the skills required.

In an attempt to better model STEM in the real-world there has been a push to integrate at least two of the disciplines within STEM education (Holmlund et al., 2018; Redman, 2017). A key issue in achieving this is that there is a relative lack of evidence regarding how to best implement integrated STEM (Blackley & Howell, 2015) as it remains a fairly new concept. This is compounded by the fact that how one school integrates subjects will often be difficult to implement within another school context. While a clarification of what is meant by either of these terms would have merit, the ship has arguably sailed, in that STEM education is already taking place to varied extents across Australia, and indeed the world, with stakeholders defining it in a myriad of ways to best suit their context and purpose. Perhaps this is not an issue, provided people within a particular context have co-constructed their own shared meaning of STEM education for their context (Bybee, 2016). However, when talking across contexts, an articulation of people's perspectives on what is meant is an important starting point or they are likely to be talking at cross purposes, which can make it difficult to implement curriculum or pedagogical reform (Holmlund et al., 2018).

Upon moving to the tertiary sector, the waters are muddied further with a lack of consistency regarding which subjects are classified as STEM. In addition to subjects studied at school level, architecture, agriculture, computing and health professions are now on offer and are sometimes classified as STEM, but not always. Agriculture is an example of a discipline which is included under

STEM by some (Australian Bureau of Statistics (ABS), 2014; Daly, Lewis, Corliss, & Heaslip, 2011; Soriano & Abello, 2015) yet omitted by others (OCS, 2012). The issue is not unique to Australia but may be seen internationally, for example through the inclusion (Argentina, China, Israel, New Zealand and the US) or exclusion (East Asian countries and Russia) of medicine as a STEM discipline (Marginson et al., 2013). The level of education considered under STEM also poses complications, with inconsistency around whether it includes university and non-university qualifications, with some including any profession that involves scientific or technical skills. Under this definition, trades such as construction, plumbing and manufacturing technicians could then be included (Harris, 2014). This lack of clarity around which disciplines and qualifications count as STEM disciplines and qualifications makes an analysis of what STEM is, and what is happening within STEM, incredibly challenging, if not impossible.

To add further to the lack of clarity, there has been a push in recent years to broaden STEM and rename it STEAM, with the A signifying the Arts. Its inclusion is based on the premise that the Arts represent a focus on key creativity-related components that are vital for a comprehensive education and success in the workplace (Daugherty, 2013). However, this raises two important issues. First, the focus on STEM disciplines does not seek to suggest that STEM disciplines are more valuable than non-STEM disciplines, nor that the latter should be excluded from students' education. While a broader and deeper uptake of STEM subjects by students at the secondary and tertiary level necessitates a reduction of non-STEM subject uptake by some students, Australian and international experiences show that "over a whole education and career the best outcomes are likely to be derived from a balanced and plural approach to disciplinary learning" (Marginson et al., 2013, p. 30).

Second, many of the arguments being made for the inclusion of an A in STEM, such as the need for fostering creativity, demonstrate a fundamental lack of understanding of the nature of STEM subjects. Creativity has been defined as "the production of a novel and appropriate response, product, or solution to an open-ended task" (Amabile, 2013, p. 135). While the Arts have long been recognised for their creativity, the STEM disciplines all rely heavily on creativity also. For example, scientists use creativity and imagination in experimental design, making the leap from data to explanation and the design of functional theoretical models to explain phenomena (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; McComas, Clough, & Almazroa, 1998). Creativity is at the heart of innovative design solutions which help to improve existing technologies and pioneer new ones. Indeed, technology education, and design technology education in particular, is a means of providing students with experience of design and problem-solving activities which aid in the development of analogical, metaphorical, divergent and combinatorial thinking. Engineers "require creativity, imagination, and the ability to integrate different scientific, mathematical and social values and theories in novel ways" (Karatas, Bodner, & Unal, 2016, p. 2) when designing engineering solutions. Mathematicians require creativity to find novel solutions to old problems, at times through the use of new approaches (Grégoire, 2016). Creativity is clearly an important factor in all the STEM fields. One should perhaps wonder therefore why creativity within STEM disciplines is not recognised as it is within the Arts. This is not to say that the Arts cannot contribute; the Arts, Humanities, Languages and every other discipline all have unique traits which are vital for a well-rounded, liberal education.

STEAM is not the only alternative acronym, but it is perhaps the most well-known. There are also at least STREAM (the addition of reading and art), STEMM (where the second M is for medicine) and STEMSS (where the final two Ss are for social studies) (Froschauer, 2016). STEM will, however, remain the focus of this study as it is the acronym which remains the most frequently used at this stage.

With this confusion around the notion of STEM itself, it follows that conceptions of STEM skills will also be very wide ranging. This makes it almost impossible for teachers to put a focus on the development of STEM skills as there is no clear articulation of these skills.

STEM literacy

There has long been an argument for the dual foci in science education of educating future scientists and educating future citizens. In the 1980s United Nations Educational, Scientific and Cultural Organization (UNESCO) and a range of other key educational bodies around the world released reports titled *Science for All* in response to a range of economic, environmental and social issues. More students were studying science than could possibly go on to have future careers in science. In fact, such students were now the minority, and yet school science had continued to be focused on preparing the next generation of scientists. *Science for All* recognised that the majority of students would not become scientists, but did require an understanding of science for life in the modern world. An example of aims or purposes of school science recognised at this time comes from the report, *Science for all Canadians:*

1. Develop citizens able to participate fully in political and social choices facing a technological society.
2. Train those with a special interest in science and technology education for further study.
3. Provide an appropriate preparation for modern fields of work.
4. Stimulate intellectual and moral growth of students (Fensham, 2004, p. 8).

Arguably it is the second of these which has dominated, and in many ways continues to dominate, within science education and now STEM education (Bybee, 2016). However, points 1 and 3, whilst pertinent to science, are even more relevant in the context of STEM as the impetus for this has come from a need for more people to have a more well-developed range of STEM skills for work within and beyond STEM. Additionally, sufficient STEM literacy to deal with the scientific and technological advancements of modern society must be developed. While it is hoped that item 4 is a result of education, it is generally not an explicit focus and this is potentially problematic, particularly in light of the advancements in STEM that even now enable genetic editing of organisms, the continued development of artificial intelligence, increasingly effective biological weapons and so on.

Whilst these issues have primarily been discussed within the context of science education, they are now being considered in the context of STEM education (Sjostrom, 2017). It has long been argued that not everyone will become a scientist yet will benefit from scientific literacy (Fensham, 2004). It is now asserted that while most students may not pursue a STEM career, they will benefit from STEM literacy in their daily lives. This is particularly true in light of the increasing degree to which technology is integrated into all facets of life (Bybee, 2016; Holmlund et al., 2018; Timms et al., 2018). This broad utilisation of STEM literacy was reflected in an OCS (2013a) paper that discussed the benefit that may be gained by widespread STEM literacy throughout the community. The National Research Council (NRC) defined STEM literacy as "the knowledge and understanding of scientific and mathematical concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity" (1996, p. 2). It is widely accepted that there is a need to increase STEM literacy for all people. Content knowledge alone is insufficient in achieving this objective. A range of skills must also be developed (Breiner et al., 2012; Gough, 2015; Peters-Burton, 2014). The need for a range of skills to make someone STEM literate justifies a consideration of STEM literacy when trying to identify STEM skills suitable for development within high schools.

STEM literacy is more than just the sum of scientific literacy, technological literacy, engineering literacy and mathematical literacy. However, it is prudent to first consider what each disciplinary literacy contributes. Zollman (2012) compiled literacy definitions for each STEM discipline from a range of key professional organisations. Some of these organisations have since updated their scientific and mathematical literacy definitions, therefore the definitions in Table 1 are a combination of those used by Zollman (2012) and those that have been released more recently.

Table 1 – Definitions of STEM literacies

Literacy	Definition
Scientific literacy	Ability to use scientific concepts and processes in explaining phenomena and interpreting data and evidence when making personal and collective decisions that affect issues such as those related to the environment, health and technology, as well as participation in civic and cultural affairs and economic productivity (NRC, 1996; OECD, 2017).
Technological literacy	Ability to use, understand and evaluate technology, use technological principles to develop solutions and recognise that society and technology shape one another (International Society for Technology in Education, 2000; International Technology Education Association, 2007; National Assessment Governing Board, 2010).
Engineering literacy	Apply mathematical and scientific principles to design, manufacture, and operate efficient and economical systems for the benefit of society (Accreditation Board for Engineering and Technology, 2010; OECD, 2003b).
Mathematical literacy	Ability to utilise mathematics to solve problems and make decisions within the context of private, occupational and social life and as a reflective citizen (National Council of Teachers of Mathematics, 2000; OECD, 2017).

As indicated by Zollman (2012), there are overlaps in these definitions. Science and mathematics are more strongly focused on knowledge and understanding of various concepts and processes. Engineering and technology on the other hand highlight the necessity of being able to actively use and apply this knowledge. Each area of literacy as presented in Table 1 highlights the use of the discipline in decision-making, at both a personal and societal level, with the exception of the engineering definitions, which do not mention it explicitly. Having said this, it is certainly able to be implied, for example in deciding how to utilise materials economically. This focus on economic productivity is clear within the scientific literacy definitions also. The other key area of consensus is the development of solutions to achieve goals. In defining ‘literacy’ more broadly, Yore, Pimm, and Tuan (2007, p. 567) argue that it

> involves being familiar with and a proficient user of the relevant disciplinary discourse and practices. This involves discourse communities’ vocabulary, language traditions, conventions, practices and procedures, cognitive and metacognitive actions, emotional dispositions, and technologies and tools used to construct and communicate discipline-specific knowledge and claims.

Thus being literate in a discipline requires both an understanding of the discourses and the content of the discipline (Yore et al., 2007). Furthermore, to be STEM literate does not merely imply literacy in each of these four domains, as “the total is much more than the sum of the individual parts”

(Zollman, 2012, p. 15). It is clear then that to come to an appreciation of what STEM literacy really means, the nature of each of its component disciplines must be understood and their resultant capacity for interconnection understood. Bybee (2016) suggests that

> STEM literacy refers to an individual's:
>
> - Knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues;
> - Understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry and design;
> - Awareness of how STEM disciplines shape our material, intellectual, and cultural environments; and
> - Willingness to engage in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen (p. 5).

This definition typifies what is found in the literature with respect to STEM literacy. It reflects the fact that STEM literacy involves the integration of concepts and disciplinary practices across science, technology, engineering and mathematics. Furthermore, that it is coupled with associated knowledge and skills to enable the creation of innovative solutions to complex problem solving. Finally, that it involves evidence-based reasoning within decision-making on societal, economic and personal levels (Bybee, 2016; Zollman, 2012). In order to cultivate a STEM-literate society, a focus on the many components that together enable a person to be truly STEM literate must be developed from the earliest opportunity – when the person is still at school.

STEM Education in Australia

Despite STEM education being introduced and focused upon internationally since the early 2000s, a focus on STEM was acquired much later in Australia. The Queensland Government was the first in Australia to recognise the importance of STEM education (Redman, 2017), with the country as a whole only showing real momentum from 2013, when the OCS and Australian Industry Group started releasing reports focused on STEM education. In December 2015, the *National STEM School Education Strategy 2016-2026* was released. Since that time, all states and one of two territories have gone on to develop their own STEM strategies (Murphy et al., 2019).

Murphy et al. (2019) conducted an analysis of the STEM strategies being used by Australia states and territories. In so doing, they acquired each region's STEM strategies and used the following coding themes in their analysis: capabilities, dispositions, educational practices, equity, trajectories and educator capacities. Of these six themes, the first two are of particular interest in the scope of the current work, as capabilities and dispositions can be thought of as akin to skills. Table 2 displays the key details of each jurisdiction's STEM education strategy document as well as the capabilities and dispositions highlighted within each.

Table 2 – STEM education strategy documents by jurisdiction and the capabilities and dispositions outlined therein (adapted from Murphy et al., 2019, pp. 7-10; Northern Territory Government, 2018)

Jurisdiction	Author	Year	Length	Title	Acquired (by Murphy et al., 2018)[2]	Capabilities	Dispositions
National	Education Council	2015	12 pages	National STEM School Education Strategy	Web search	Creative thinking Critical analysis Problem solving Mathematical, scientific and technology literacy STEM discipline skills	Interest
Australian Capital Territory (ACT)	Uses the National Strategy						
New South Wales (NSW)	Department of Education	2017	Website	STEM	Web search and response to request	Creative thinking Critical analysis STEM discipline knowledge	Curiosity Aspirations
Northern Territory (NT)	Department of Education	2018	24 pages	STEM in the Territory Strategy	Web search	Collaboration Critical thinking Creative thinking Ethical problem solving Digital and coding skills Mathematical thinking Scientific literacy	Engagement Participation Aspiration
Queensland (QLD)	Department of Education and Training	2016	2 pages	A strategy for STEM in Queensland state schools	Web search	Creative thinking Critical analysis Problem solving	-
South Australia (SA)	Department for Education and Child Development	2016	12 pages	STEM Learning Strategy for DECD Preschool to Year 12	Web search	Collaboration Problem solving Interdisciplinary thinking STEM discipline skills and knowledge	-

[2] The Northern Territory's Strategic document was not available to Murphy et al (2018) as it was only published in 2018, it was thus obtained and capabilities and dispositions identified by the author.

Jurisdiction	Author	Year	Length	Title	Acquired (by Murphy et al., 2018)[2]	Capabilities	Dispositions
Tasmania (TAS)	Department of Education	2017	1 page	STEM Framework	Response to request	Collaboration Creative thinking Critical analysis Problem solving Project management Self-direction STEM literacy Understanding of relevance of STEM in society and world of work	Resilience Growth mind-set
Victoria (VIC)	Department of Education and Training	2016	24 pages	STEM in the Education State	Web search	Experimenting Hypothesising Investigating Problem solving Creative thinking Critical analysis Ethical thinking STEM discipline skills and knowledge	-
Western Australia (WA)	Department of Education	2016	19 pages	STEM Support Plan 2016/17	Response to request	Collaboration Communication Creative thinking Critical analysis Independent thinking Integrated knowledge Problem solving ICT skills Numeracy	-

Since the release of the National STEM School Education Strategy, every jurisdiction has developed their own, with the exception of the ACT (which has adopted the National STEM Strategy). Most of these strategies are shorter than or equal to the National Strategy in length, with VIC and WA having longer and presumably more detailed strategic documents. As the STEM capabilities therein are of the greatest relevance to the study, their portrayals across the strategy documents will now be compared.

The National Strategy touched on five STEM capabilities, most but not all of which are repeated in the separate jurisdiction documents. Creative thinking and critical analysis were acknowledged within each of the strategies apart from SA. Problem solving was specifically stated in each document apart from NSW. Mathematical, scientific and technological literacy was identified within the National document while NT referred only to scientific literacy. TAS was the sole jurisdiction to mention STEM literacy. However, with STEM literacy, TAS also included understanding of relevance of STEM in society and world of work, which is arguably a component of STEM literacy itself (Bybee, 2016). The final capability outlined in the National document was STEM discipline skills. This was omitted from the QLD, TAS and WA documents, was termed STEM discipline knowledge (rather than skills) in NSW and NT and broadened to include discipline skills and knowledge in the SA and VIC documents.

In addition to these aspects, the NT, SA, TAS, VIC and WA STEM strategy documents outline some additional STEM capabilities. Collaboration is mentioned in the NT, SA, TAS and WA documents. NT includes ethical problem solving and has a very strong focus on digital and coding skills. SA further adds interdisciplinary thinking while TAS also highlights project management and self-direction. The VIC document includes ethical thinking along with experimenting, hypothesising and investigating. Finally, WA also includes some components which are arguably STEM discipline skills, namely ICT skills and numeracy, but also includes communication, independent thinking and integrated knowledge.

Murphy et al. (2019) suggest that collectively Australia's STEM education strategies align with the literature. However, no single strategy addresses all key themes to a deep enough extent. They note 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 (Murphy et al., 2019, p. 13).

While having a National STEM strategy and various jurisdictional strategy documents is a start, it would be beneficial for these strategies to more thoroughly cover the key themes from the literature. A stronger focus on ensuring that curriculum implementation allows strong skill development and a developing understanding of the real world applications of STEM would also be very beneficial (Chapman & Vivian, 2017). Most teachers do not have access to the literature upon which these strategies are based and thus rely on the content contained within the strategic documents. It may also be more useful for each strategy to share a greater number of things in common so that teachers and students who move across jurisdictions do not experience a degree of conflict between the focus of one jurisdiction to the next.

Having presented a brief history of the STEM education movement and the notion of STEM literacy, the focus will now shift to the place of STEM within the Australian Curriculum.

STEM disciplines within the Australian Curriculum

The quote from the Australian Industry Group (2013) at the start of Chapter 1 indicated that the STEM skills of school leavers warranted particular attention. By way of determining which skills are likely to be developed within Australian students' education, the curriculum is a good starting point. However, it is worth noting that a lot may change between what is written in the curriculum and how it is enacted within the classroom.

The concept of a national curriculum within Australia has been held for a long time, though it is only in recent years that it has become a reality with the *Shape of the Australian Curriculum* being approved by state and territory Ministers in 2009. The Australian Curriculum was developed by ACARA and is available on the Australian Curriculum website, with separate sections for Foundation to Year 10 and Senior Secondary (Years 11 and 12). The Australian Curriculum has three key branches: general capabilities; cross-curriculum priorities; and the learning areas. The general capabilities and cross-curriculum priorities are to be integrated into each learning area when appropriate (ACARA, 2012b). These three branches will be briefly outlined with the focus of the research being placed upon Years 7-10 as these are the final compulsory years of science and, in some states, of mathematics too. It is also the time when students start are first able to choose electives in line with careers they think they may pursue.

The general capabilities "play a significant role in the Australian Curriculum in equipping young Australians to live and work successfully in the twenty-first century" (ACARA, 2013c, para. 1). The general capabilities are: literacy, numeracy, ICT capability, critical and creative thinking, personal and social capability, ethical understanding; and intercultural understanding (ACARA, 2013c). The three cross-curriculum priorities are: Aboriginal and Torres Strait Islander Histories and Culture; Asia and Australia's Engagement with Asia; and Sustainability and, as the name suggests, are designed to flow across all of the curriculum (ACARA, 2011).

In terms of learning areas that fall under the STEM classification, the Australian Curriculum contains the following:

- Mathematics – compulsory from Foundation to Year 10 with content organised into three overarching content strands: number and algebra; measurement and geometry; and statistics and probability. Four proficiency strands describe the thinking and doing of mathematics: understanding; fluency; problem-solving; and reasoning (ACARA, 2015m).
- Science – compulsory from Foundation to Year 10 covering biological, chemical, earth and space, and physical sciences. It is organised into three interlinked strands: science understandings, science as a human endeavour and science inquiry skills (ACARA, 2015r)
- Technologies – this learning area is comprised of Design and Technologies, in which students "generate and produce designed solutions for authentic needs and opportunities" (ACARA, 2015t, para. 1); and Digital Technologies, in "which students use computational thinking and information systems to define, design and implement digital solutions" (ACARA, 2015t, para. 1). The Technologies learning area is designed for both subjects to be studied from Foundation to Year 8, with each subject becoming an elective in Years 9 and 10. They are both organised around two strands: knowledge and understanding; and process and production skills (ACARA, 2015v).

Mathematics and Science are quite clearly covered, Technology and Engineering a little less so. The learning area of the Technologies includes Design Technologies, which is as close as the Australian Curriculum gets to covering engineering, but it is not the sole focus. Digital Technologies clearly cover those aspects of Technology but, again, not all aspects of Technology, as a discipline, are necessarily included.

The content and skills articulated within the general capabilities and cross-curriculum priorities as well as within each of the STEM learning areas, will be examined by way of determining the degree to which each learning area facilitates the development of STEM skills. This is necessary as it provides insights into the types of skills that are likely to be developed within Australian soon-to-be school leavers.

Summary of Chapter 2

The acronym STEM has been used to an increasing degree over the last two decades. However, what is meant by the acronym, beyond the four disciplines the letters stand for, is not clear and is further complicated by the use of other related acronyms. Even the decision to focus on STEM alone does not fully simplify matters as differences in perspective remain in terms of what is meant by STEM qualifications, STEM jobs and STEM education. Given the diversity of viewpoints on each of these, skills that may be identified as STEM skills are similarly varied. However, what is clear is that STEM skills are deemed important for all Australian students to develop. Furthermore, STEM literacy, like scientific literacy before it, is now seen as being important for all citizens. Thus, a clear idea of what STEM literacy is, what STEM skills are and how to develop them within a school context, needs to be explored.

The last decade has seen many developments in Australia's approach to STEM education. In 2015 a National STEM Education Strategy was released to guide STEM education from 2016-2026. This has been adapted by all states and territories with the exception of the ACT into a strategy designed specifically for their jurisdiction. However, the benefit of this customisation is questionable given all jurisdictions are meant to be working towards the National strategy. The similarity between the STEM skills stated within these strategic documents and skills outlined in the literature needs to be determined by way of concluding whether these strategic documents are placing emphasis in the right place, especially in terms of the skills that are focused upon.

As the STEM skill levels of school leavers has been identified as problematic for the Australian workforce (Australian Industry Group, 2013), it is necessary to determine what skills employers are looking for and the prominence of these skills within the Australian Curriculum. The Mathematics, Science and Technologies learning areas of the Australian Curriculum cover the S, T and M of STEM quite effectively. However, the E is largely overlooked, with the exception of some incorporation of engineering principles into Design and Technologies. These learning areas are presented separately, though are linked by the general capabilities and cross-curriculum priorities which stretch across all learning areas. If STEM skills are not clearly articulated within the curriculum, they are unlikely to be a focus for teachers and therefore unlikely to be consciously focused upon, hence the analysis of the curriculum itself.

In Chapter 3 the focus shifts to an examination of the two key arguments used to justify the focus being placed on STEM within education today and why STEM skills are important skills for all Australian high school students to develop.

Chapter 3 – The Importance of STEM from Educational and Workforce Perspectives

Introduction

There is a worldwide focus upon STEM and STEM education, and while there are subtle nuances in how this plays out in different countries, the argument generally focuses on the perception that excellence in STEM is necessary to compete globally (Blackley & Howell, 2015). As a result of this, there are a plethora of governmental and industry reports on STEM from educational as well as workforce perspectives and so these reports are considered here to be part of the literature. The Australian Council of Learned Academies (ACOLA) conducted a series of studies under the broad series title of *Securing Australia's Future*. The second of these reports was titled *STEM: Country Comparisons*. Its analysis of country and regional reports from a wide range of nations found "almost universal governmental preoccupation" (Marginson et al., 2013, p. 53) with participation rates and level of achievement within STEM subjects at the secondary and tertiary levels. There is also a strong focus on building STEM skills, particularly with respect to their role in research and development as well as industry innovation (Marginson et al., 2013). The prominence of such a report on STEM indicates the importance that the Australian Government places on all facets of STEM and its contribution to securing Australia's future.

In November 2014 the OCS released the *Benchmarking Australian Science, Technology, Engineering and Mathematics* paper. It was commissioned to help the Australian Government to

> get a 'fix' on our performance – not an easy one, against 'the world', but a more challenging one, against nations that, like us, are essentially free-market economies with serious science engagement. We often depict Australia as 'punching above its weight' in research performance… [but] where we stand relative to 'the world' is of marginal value only, serving mainly to draw our attention from where it should be, which is on how to improve (OCS, 2014a, p. iii).

The paper's findings highlight Australia's performance across a range of areas, raises some important questions and provides valuable information for Australia in deciding what to do when moving forward in STEM.

The report focuses on countries with broadly similar governance systems and stages of development across three regions:

- Western European countries (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Norway, Sweden, Switzerland, United Kingdom (UK)) referred to as the EU11;
- Countries from the Asia Pacific region (China, India, Indonesia, Japan, Malaysia, the Philippines, Singapore, South Korea, Thailand, Vietnam and New Zealand); and
- The US and Canada (OCS, 2014a).

The report outlined how Australia performed relative to these countries across eight key focus areas: research performance; highly cited research; patents; research funding; international collaboration; the STEM research workforce; higher education; and schools (OCS, 2014a). The last of these will be the focus for this thesis.

The *Benchmarking* report recognises that the STEM pipeline starts in schools and that it is vital to ensure that students are given the best opportunity to excel in STEM fields. This requires Australian STEM teachers at all levels to be trained and supported to deliver a first-class curriculum which focuses on inquiry, problem-solving and higher order thinking. Several data sources were used to determine how Australian students are performing in schools relative to their international peers but the key focus was placed on performance in two key international tests, PISA and TIMSS (OCS, 2014a).

Governments around the world are focused upon STEM for a variety of reasons that can broadly be grouped into two categories. The first forms the educational argument. This is based upon the perception that falling standards in international tests reduces a country's capacity to compete internationally. Being scientifically (and mathematically) literate is no longer seen to be enough for the 21st century, we need our future citizens to be STEM literate, regardless of whether they ultimately end up working in or outside of the STEM field. This is because many skills typically associated with STEM are needed across a wide variety of occupations (Salzman & Benderley, 2019; Timms et al., 2018; Waite & McDonald, 2019).

The second key reason for a focus on STEM is the workforce argument, which is concerned with the increasing number of jobs which require an understanding of STEM fields and the insufficient number of qualified people for STEM positions. This is often referred to as the STEM worker paradox (ACOLA Secretariat Ltd, 2016; Kramer et al., 2015; Marginson et al., 2013). The focus on STEM workers is intertwined with a worldwide STEM skills policy agenda that

"is driven by the:
- need to lift the quality and supply of human capital,
- need to increase the workforce capability to compete globally in technological innovation,
- skills shortages, and
- desire to lift overall levels of numeracy, science and digital literacy" (OCS, 2013b, p. 1).

Proficiency within STEM professions is becoming synonymous with a strong national economy. STEM jobs are seen as being vital for innovation and STEM skills are seen as being required for success in what may be termed the Fourth Industrial Revolution (Krajcik & Delen, 2017; Waite & McDonald, 2019). However, despite the ever-growing need for workers in the STEM sector, there is an interesting paradox at play in countries such as Australia in which STEM graduates are having difficulty gaining employment upon graduation (Birrell, 2014).

While the objective of this thesis is to examine the development of STEM skills within the Australian high school context, the Australian STEM workforce is a key focus of governments and is thus worthy of examination by way of providing a more holistic context for this work. Additionally, a key role of schools is to prepare individuals to contribute productively to the workforce. Therefore, it is important to be aware of what employers are looking for so that schools can better prepare today's students for the workforce of today and tomorrow. What follows is an overview of the two primary arguments used to warrant the focus placed on STEM: the educational argument; and the workforce argument.

The educational argument

It is increasingly common within government reports and political speeches to hear the sentiment that Australian students are falling behind other nations in international testing. Performance of students on tests such as PISA and TIMSS are a commonly used metric to determine how the STEM pipeline is faring at the school level by determining of the proportion of students who have the requisite knowledge and skills to work in STEM fields (Salzman & Benderley, 2019). For example,

> Australia has a long tail of underperforming students in STEM, with 30 per cent scoring below minimal levels of competency.[3] In addition there has been a steep decline in student commitment to science and maths between Years 4 and 8, and a declining percentage of Year 12 students participating in STEM (OCS, 2013b, p. 1).

The following section seeks to explore Australian student performance in PISA and TIMSS using data from the inception of each (2000 and 1995 respectively) through to the 2015 tests, which were released in December 2016[4].

The effect of international testing – PISA and TIMSS

One of the key metrics used by the OCS in their *Benchmarking* (2014) paper to assess the performance of Australian schools in STEM was student performance in two international tests. The first, conducted by the OECD, is PISA. The second, conducted by The International Association for the Evaluation of Educational Achievement (IEA), is TIMSS. The IEA also administers another international test, the Progress in International Reading Literacy Study (PIRLS) (IEA, 2016), though as it focuses on reading literacy alone it was omitted from this work.

[3] In TIMSS 2011.

[4] Note that PISA was conducted in 2018 and TIMSS in 2019 but full results were not available at time of writing. As comprehensive data analysis for these most recent iterations were unavailable it was decided to consider PISA and TIMSS up to and including the 2015 round of testing in which both tests were conducted.

A focus on these international tests by way of assessing a nation's cognitive ability is not unique to Australia. This is perhaps largely due to

> the relationship between direct measures of cognitive skills and long-term economic development. The evidence points to differences in cognitive skills as an explanation of a majority of the differences in economic growth rates across OECD countries (OECD, 2010, p. 10).

The apparent link between performance in tests of this nature and a country's economic competitiveness helps to explain why so much stock is put in the results each cycle. Furthermore, these links to the economic wellbeing of a nation are particularly emphasised within the STEM field as a result of the links between STEM and sustainable development and innovation (Marginson et al., 2013). Thus, it is perhaps no surprise that countries around the world, including Australia, rely on tests such as PISA and TIMSS to assess how their country is faring in STEM. A desire to improve performance in these STEM-related international tests underpins many international educational reforms. For example, the Australian results from PISA 2012 and TIMSS 2011 were a motivating factor for the Review of the Australian Curriculum conducted in 2014 (Australian Government Department of Education, 2014). However, while results in tests such as PISA and TIMSS are often used to decry failing education systems, these claims are rarely backed up with evidence regarding whether the educational system is in fact to blame (Salzman & Benderley, 2019).

PISA

PISA testing was first implemented in the year 2000 as a research instrument for the OECD countries but has since been expanded to include over 72 countries and economies (some of which are 'partners' that lie beyond the OECD) in the fifth round of testing conducted in 2015 (OECD, 2016). The inclusion of non-member countries and economies highlights the importance placed on the test, which is utilised as an international benchmarking tool "designed to monitor outcomes over time and provide insights into the factors that may account for differences in performance within and between countries/economies" (Breakspear, 2012, p. 5).

Every three years results are published by the media, at both the national and international levels. This stimulates a discussion about school reform, how rival nations are competing, and whether a country has risen up or slid down the rankings (Breakspear, 2012; Marginson et al., 2013). Following the first three rounds of testing, conducted in 2000, 2003 and 2006, Grek (2009) examined the 'PISA effect' within the national contexts of a range of countries and found three types of reaction to PISA results.

The Finnish education system has drawn strong attention ever since the release of the first PISA results in 2001. However, the success of Finnish students demonstrated a reaction now known as

'PISA-surprise', with the country pleasantly surprised by their relative success. Subsequent policy action within the country appeared to therefore focus primarily on securing constant improvement. This response was contrasted with a 'PISA shock' response, perhaps best typified by Germany's reaction to placing 20th out of 32 nations in 2000 (Grek, 2009). However, a similar response was also observed in Denmark in 2000 when, despite their well-funded education system, they attained only average results; and in Japan in 2003, when they performed significantly worse than they had done in 2000 (Breakspear, 2012). In each of these nations, the lack of correlation between expected and actual results made a major impact at both the public and policy level, prompting large-scale educational reforms. A third response type was identified within the UK which has been termed 'PISA-promotion'. This response is typified by a lack of negative reporting by the media, for example, the media in the UK did not report on the large gap between pupils of high versus low socioeconomic backgrounds in 2000 and 2003. Instead, the positive results were highlighted and used to reassure society and policy-makers that their current educational approach was working (Grek, 2009).

The media in Australia has tended to portray results in a negative light, particularly in the wake of continued decreases in performance in recent cycles. For example, some headlines following the release of the 2015 results were:

Why Australia's PISA results are a catastrophe (Buckingham, 2016)
Australian school students two years behind world's best (Bagshaw, 2016)
Australian schools are in 'absolute decline' globally, says PISA report (Hunjan & Blumer, 2016).

Thus, the reaction in Australia is arguably of a fourth type, 'PISA-envy', in which the media highlights Australia's negative performances and praises foreign education systems. For many years Finland had the educational system to which everyone aspired, much to the Finns' surprise. However, following their relative slip in recent years, the focus has turned to how to emulate East Asian countries who have since dominated the rankings (Dinham & Lomas Scott, 2012).

The Australian Council for Educational Research (ACER) releases detailed reports following each PISA cycle regarding Australia's performance. Some key findings pertaining to Australian students' scientific and mathematical literacy are discussed below because results in PISA and TIMSS are frequently used as a measure of Australian students' STEM skills.

PISA – Scientific Literacy. Australia's average score of 510 in 2015 was significantly[5] higher than the OECD's average of 493. Nine countries performed at a level significantly above Australia while eight countries performed at a level not significantly different from that of Australia. The remaining countries all performed significantly lower than Australia. Australia had one of the broadest ranges of student achievement (336 points) with a higher proportion of high achievers (11%) than the OECD average (8%) and a lower proportion of low achievers (18%) than the OECD average (21%). Only 61% of Australian 15 year olds attained the national proficient standards in scientific literacy, indicating that a staggering 39% did not (S. Thomson, De Bortoli, et al., 2016).

While the OECD average in 2015 was not significantly different from that of 2006 (the last cycle in which scientific literacy was the major domain), the relative positioning of nations changed quite drastically. Australia was one of 13 countries which "showed a significant decline in their scientific literacy performance between 2006 and 2015" (S. Thomson, De Bortoli, et al., 2016, p. xi) with Australia declining by 17 points over this time period. The overall trend in Australia's average score in PISA scientific literacy is shown in Figure 1.

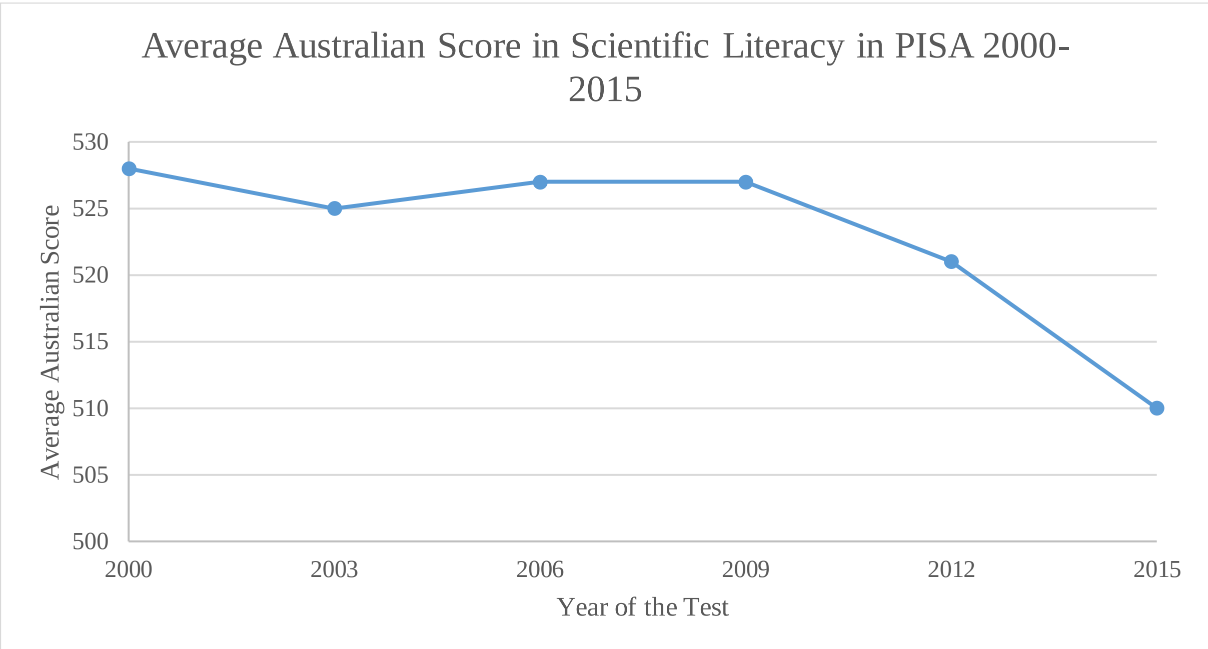

Figure 1 – Average Australian Performance in Scientific Literacy in PISA 2000-2015 (data taken from Lokan, Greenwood, & Cresswell, 2001; S. Thomson, Cresswell, & De Bortoli, 2004; S. Thomson & De Bortoli, 2008; S. Thomson, De Bortoli, & Buckley, 2013; S. Thomson, De Bortoli, Nicholas, Hillman, & Buckley, 2011; S. Thomson, De Bortoli, & Underwood, 2017)

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[5] The term 'significantly' refers to statistical significance at the level used by ACER, "to describe a difference that meets the requirements of statistical significance at the 0.05 level, indicating that the difference is real, and would be found in at least 95 analyses out of 100 if the comparisons were to be repeated." (S. Thomson, De Bortoli, et al., 2016, p. vii).

While Australia ranked 14th overall in 2015 and was well above the OECD average of 493, the results do not paint a positive picture. The OECD average for the 2006 to 2015 period experienced a non-significant decline. Australia, however, demonstrated a significant decline over the same period, the 10th greatest decline of all participating countries.

PISA – Mathematical Literacy. The Australian average score of 494 points in 2015 was higher than the OECD average of 490 points for mathematical literacy, but not statistically significantly higher. Australia's performance was significantly lower than 19 countries and not significantly different from another ten. Australia had the same proportion of high performers as the OECD average (11%) and almost as many low performers (22% compared with the OECD average of 23%). There were 306 points between students in the 5th and 95th percentile in Australia compared with the OECD average of 293. Only 55% of Australian students attained the National Proficient standard for mathematical literacy. While the spread was slightly smaller than in scientific literacy, there is a higher proportion of low performing students and barely half attained a proficient level in mathematical literacy (S. Thomson, De Bortoli, et al., 2016).

Again, the OECD average did not differ substantially between 2012 (when mathematics was the focus domain) and 2015. But while eight countries showed significant improvement, Australia was one of ten countries whose performance decreased significantly between 2012 and 2015. Indeed, Australian mathematical literacy scores have decreased since 2000, and to an increasing degree, leading to Australia's 2015 score being 39 points lower than the score in 2000, as shown in Figure 2.

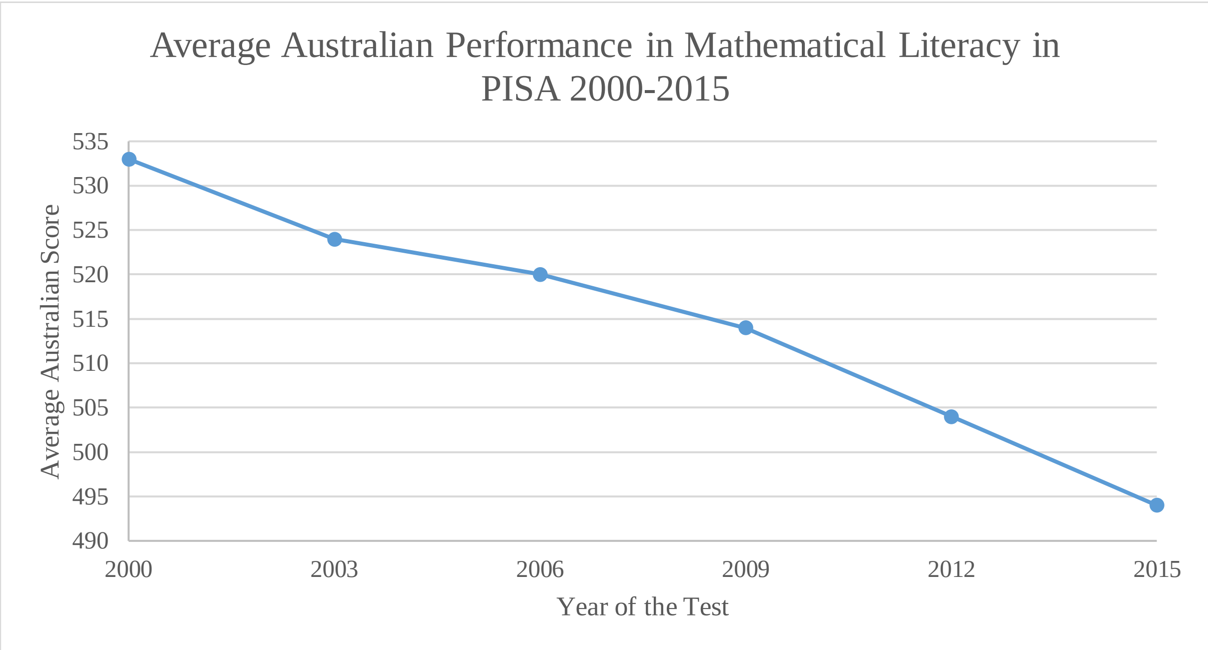

Figure 2 – Average Australian Performance in Mathematical Literacy in PISA 2000-2015 (data taken from Lokan et al., 2001; S. Thomson et al., 2004; S. Thomson & De Bortoli, 2008; S. Thomson et al., 2013; S. Thomson et al., 2011; S. Thomson et al., 2017)

The general picture for mathematical literacy is more problematic than that of scientific literacy with Australia ranked 25th, only five places and 13 points above the OECD average. The significant declines shown in Figure 2 present due cause for reflection on the state of mathematical education within Australia.

PISA – Overall. The performance of Australian students in PISA over time is not a particularly positive story. While Australia remains significantly above the OECD average in both scientific and mathematical literacy, Australia's performance has declined while other nations have forged ahead. This makes reaching former Prime Minister Julia Gillard's goal that "by 2025, Australia should be ranked as a top 5 country in the world in reading, science and mathematics" (2012, para. 2) increasingly unrealistic.

Australia routinely performs more strongly than the US in each literacy area, another country in which concern over PISA results is common. Following the 2012 PISA testing, a report by Salzman, Kuehn, and Lowell (2013) argued that while the average performance of US students has been declining relative to other nations, the US continues to produce a large share of students who rank at the top. Furthermore, while countries such as Finland and Singapore routinely rank highly, their populations are such that the actual number of students they produce who go into STEM fields is negligible when compared with the US (Lowell & Salzman, 2007; Salzman et al., 2013).

The US accounts for 21.7% of all top performing OECD students in scientific literacy. It can therefore be argued that it is somewhat misguided to focus on average test scores and relative rankings if the point of interest is preparedness of students for future work within STEM fields. While the average US student may not perform as well as one from Finland or Singapore, there is a greater number of students within the US who are performing highly on international tests and thus, by that argument, are ready to pursue a STEM career. Rather than focusing only upon average test scores, more attention perhaps ought to be paid to the number of high performing students and the vacancies within the STEM workforce. This would also require a degree of tracking of the careers that the students taking the test ultimately end up pursuing, to see if students who perform strongly in the science and mathematics components of PISA are any more likely to enter a STEM profession. This is not yet inherent within PISA.

While Australia's population is nowhere near the size of the US, it is worth remembering that a strong and competitive STEM workforce is not predicated on all students performing strongly in a test such as PISA. Of the Australian students who completed the PISA tests in 2015, 11% were classed as high-performing students in each of the literacy areas, a value greater than or equal to some countries who significantly outperformed Australia. If it is the top performing students whom stakeholders are looking to attract into STEM, then there is a pool from which to draw. Indeed, Australia accounts for 2.1% of the top performing students while Singapore, the top performing country based on averages, only accounts for 0.8% of the top performing students. There may well then be enough Australian students with the highest levels of proficiency to enter STEM disciplines. Arguably, the larger focus ought to be placed on the substantial proportion of low performing students, 18% in scientific literacy and 22% in mathematical literacy. If the aim is to develop a STEM-literate Australian society, it is these low performing students and the large gap between the top and bottom that warrants attention.

TIMSS

TIMSS commenced in 1995 and is conducted every four years. It is a test taken by students in Year 4 and Year 8. TIMSS examines mathematics and science only (the IEA uses PIRLS to assess reading literacy) and seeks to align with school curricula from participating countries at the Year 4 and Year 8 levels. It collects data regarding students, teachers, schools and education systems to examine the achievement of students within the context of their educational system (S. Thomson, Wernert, et al., 2016). TIMSS uses the curriculum being implemented in different countries as its major organising structure. Consideration is also paid to various factors that have an impact upon how the curriculum is lived out, such as national, social and classroom contexts, and the characteristics and outcomes of the students.

A total of 38 countries participated in the Year 4 and/or Year 8 components of TIMSS 2015. The Australian results were released in late 2016 with a negative tone adopted by Australian media. Many reports on the day after the release of results claimed the results to be a ‘wake-up call’ and drew attention to the fact that Kazakhstan was now outperforming Australia (Conifer, 2016; Knott, 2016b). However, this ignores the fact that Kazakhstan had beaten Australia previously (Mullis, Martin, & Foy, 2008). Also, following Kazakhstan’s own wave of ‘PISA-shock’ after ranking 56th in mathematics in 2009, despite a strong performance in TIMSS two years before, a national education action plan was put in place which sought to modernise their approach to teaching and learning. Kazakhstan also established a number of centres of excellence for talented students, worked on improving their assessment system and supported teachers in their pedagogical development (OECD, 2014). So perhaps Australia should not be surprised that the country satirised by *Borat* is performing well in international testing, but should instead focus upon how Australia can improve its own performance in the future (Conifer, 2016). Of far greater concern than Australia’s performance relative to Kazakhstan is the fact that, while Australia’s results have essentially remained stagnant over the past 20 years of TIMSS testing, a number of countries that Australia used to outperform now outperform Australia (S. Thomson, 2016).

Results from Year 4 and Year 8 were considered, even though the focus of this thesis is Years 7-10, as the cohort who participates in Year 4 is the same as that which participates in Year 8 four years later. Thus, an indication of how a group of students have progressed in that time period is able to be obtained.

TIMSS – Science. In 2015, Year 4 students from Australia significantly outperformed students in 17 countries and were also outperformed by students in 17 countries thus performing not significantly differently from the remaining 12 countries. Only 8% Australian of students attained the Advanced international benchmark, but 75% of students achieved the proficient standard for Australia.[6]

Year 8 Australian students significantly outperformed 20 countries and were outperformed by a smaller margin than in Year 4, this time only 14 countries, performing non-significantly differently from the remaining four. It must be noted that fewer countries participated in Year 8 than Year 4. Again, a slightly lower proportion reached the Advanced international benchmark in science in Year 8, 7%, and a lower 69% attained the proficient standard for Australia.

On average there has been a less profound difference in Year 4 versus Year 8 performance in Science over the past five iterations of TIMSS. Both years have shown fluctuations, with a stronger performance by Year 4 and weaker by Year 8 in 2015 than 2011, indeed the Year 8 2015 score is the lowest recorded by any year group in any year of testing, while Year 4 improved greatly from 2011 but did not reach the heights of 2007.

[6] The Australian Curriculum, Assessment and Reporting Authority (ACARA) selected the TIMSS Intermediate benchmark to be used as the national proficient standard (S. Thomson, 2016)

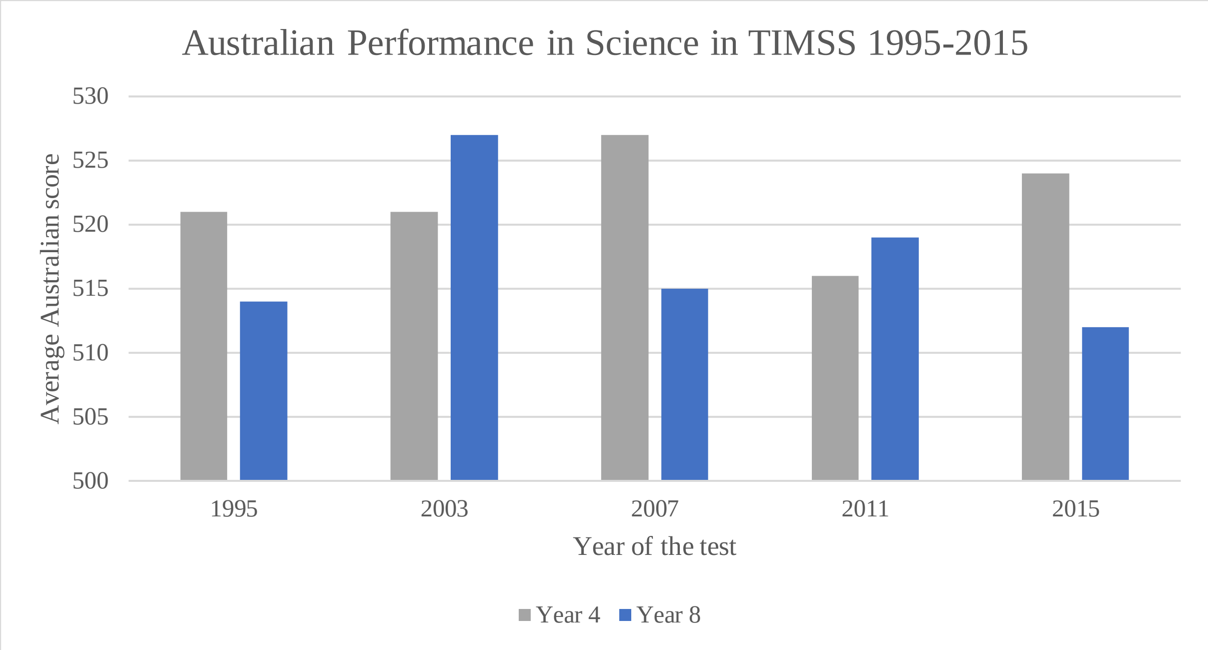

Figure 3 – Australian Performance in Science in TIMSS 1995-2015 (data taken from S. Thomson, Wernert, et al., 2016)

TIMSS – Mathematics. At the Year 4 level, Australia's score of 517 was around the middle of the pack, with 21 countries performing significantly better, 20 significantly worse, and the remaining seven not significantly different from Australia. Only 9% of Australian students achieved the Advanced International benchmark while 70% attained Australia's proficient standard (S. Thomson, Wernert, et al., 2016).

In Year 8, Australian students significantly outperformed 21 countries and were only significantly outperformed by 12, with the remaining five countries' achievement not being significantly different to that of Australia. However, fewer countries participated in Year 8 mathematics than Year 4, hence relative rankings are not directly comparable. Of concern is that fewer Australian students attained the highest benchmark in Year 8, only 7% compared with greater than one-third of students compared with the top five countries. Furthermore, only 64% of Australian Year 8 students attained the proficient standard (S. Thomson, Wernert, et al., 2016).

TIMSS has been administered for 20 years and, as seen in Figure 4, it can be observed that Australian Year 4 students' performance improved greatly from 2003 to 2007 and has held steady since then. Year 8 students' performance dropped in 2007, rebounded in 2011 and is unchanged in 2015, showing far less variability over time. The Year 4 cohort of one round of testing is the same as the Year 8 cohort in the following round of testing, thus Figure 4 would suggest that the students who were Year 4 in 1995 improved when tested again in Year 8 in 1999 but since then Year 8 students have performed worse than their equivalent Year 4 cohort.

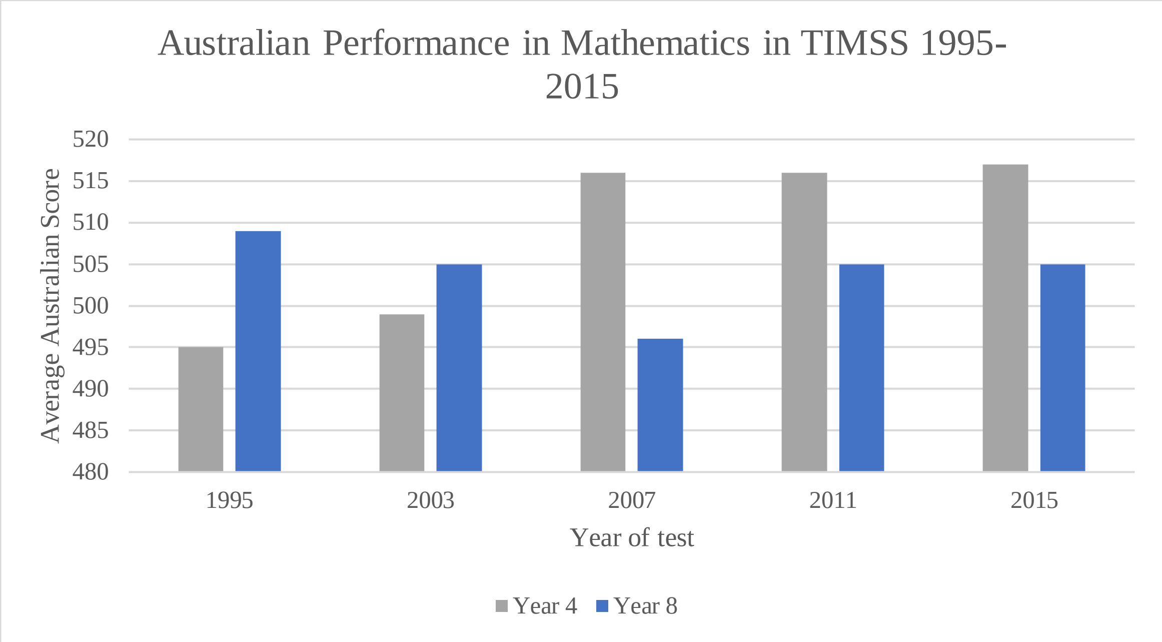

Figure 4 – Australian Performance in Mathematics in TIMSS 1995-2015 (data taken from S. Thomson, Wernert, et al., 2016)

A very small proportion of Australian students have reached the highest levels of achievement in Year 4 and Year 8. Furthermore, a greater proportion of students in Year 8 than Year 4 is attaining the lowest benchmarks, meaning that fewer students are demonstrating the ability to apply their mathematical skills as they progress through their schooling (S. Thomson, 2016).

TIMSS – Overall. Australian students' results in TIMSS have fluctuated over time, more so than in PISA where a gradual decline is apparent. All countries update their curriculum periodically, but countries do this on their own timelines. The latest results are insufficient to judge the effectiveness of the new Australian Curriculum as it was not instituted in all jurisdictions by 2015. Countries who perform strongly arguably have a more rigorous curriculum than those countries whose average performance was lower (Germain-McCarthy, 2013). If students are routinely working at a higher level, it is no surprise that they should perform better than students routinely working at a lower level. Thus, as the Australian Curriculum continues to be implemented and developed over time, a cross-country comparison of the rigour of the Australian versus other countries' curricula may be pertinent. Another area of interest worth examining, which lies beyond the scope of this work, is why Australian students' performance drops relative to their peers between Year 4 and Year 8.

Australia's performance in PISA and TIMSS compared with 'like' nations

In the OCS (2014a) Benchmarking paper, each of the 24 nations' performance was ranked as being 'Above Australia' or 'Below Australia' (or 'No data provided') on a range of metrics including PISA's mathematical and scientific literacy mean scores. As this analysis was conducted prior to the release of the 2015 data, a new analysis using the 2015 PISA and TIMSS results for these 24 nations and Australia is summarised in Table 3.

Unfortunately not all nations completed all components of both tests and data was not obtainable for some nations, thus the following points must be borne in mind when reading Table 3 (S. Thomson, De Bortoli, et al., 2016; S. Thomson, Wernert, et al., 2016):

- Malaysia's data was not included in the Australian Council for Educational Research (ACER) PISA report "because their coverage was too small to ensure comparability" (S. Thomson, De Bortoli, et al., 2016, p. xviii);
- India and the Philippines did not participate in PISA or TIMSS;
- Indonesia was omitted from the ACER report as it attained an average score lower than Mexico, the lowest OECD country thus was placed at the bottom of each list;
- Hong Kong is the only Chinese province that participated in both PISA and TIMSS, the other two provinces (Macao and Beijing-Shanghai-Jiangsu-Guangdong) were maintained in the PISA analysis;
- the UK as a whole was reported in PISA but only England and Northern Ireland participated (separately) in TIMSS;
- Belgium, Denmark, Finland, France, Germany, Northern Ireland and Indonesia only participated in TIMSS Year 4;
- Malaysia and Thailand only participated in TIMSS Year 8; Austria, Switzerland and Vietnam participated in PISA but not TIMSS.

Table 3 – Rank order of countries included in the Office of the Chief Scientist's Benchmarking report in the scientific and mathematical literacy domains of PISA 2015 and Mathematics and Science at the Year 4 and 8 levels of TIMSS 2015.

Rank	PISA Science	PISA Maths	TIMSS 4S	TIMSS 8S	TIMSS 4M	TIMSS 8M
1	Singapore	Singapore	Singapore	Singapore	Singapore	Singapore
2	Japan	Hong Kong	Korea	Japan	Hong Kong	Korea
3	Finland	Macao	Japan	Korea	Korea	Hong Kong
4	Macao	Japan	Hong Kong	Hong Kong	Japan	Japan
5	Canada	BSJG	Finland	England	Northern Ireland	Canada
6	Vietnam	Korea	United States	Ireland	Norway	Ireland
7	Hong Kong	Switzerland	Sweden	United States	Ireland	United States
8	BSJG	Canada	Norway	Canada	England	England
9	Korea	Denmark	England	Sweden	Belgium	Norway
10	New Zealand	Finland	Ireland	New Zealand	United States	AUSTRALIA
11	AUSTRALIA	Belgium	Germany	AUSTRALIA	Denmark	Sweden
12	United Kingdom	Germany	Denmark	Norway	Finland	New Zealand
13	Germany	Ireland	Canada	Malaysia	Germany	Malaysia
14	Switzerland	Norway	AUSTRALIA	Thailand	Sweden	Thailand
15	Ireland	Austria	Northern Ireland		AUSTRALIA	
16	Belgium	New Zealand	Belgium		Canada	
17	Denmark	Vietnam	New Zealand		New Zealand	
18	Norway	Sweden	France		France	
19	United States	AUSTRALIA	Indonesia		Indonesia	
20	Austria	France				
21	France	United Kingdom				
22	Sweden	United States				
23	Thailand	Thailand				
24	Indonesia	Indonesia				

Note: The nations are listed in rank order with the darkest shade of each column being used for nations who performed significantly better than Australia, the mid-shade for countries who were not significantly different to Australia and the lightest for countries who ranked significantly lower than Australia, (data taken from S. Thomson, De Bortoli, et al., 2016; S. Thomson, Wernert, et al., 2016).

Australia's performance relative to these nations is arguably of greater concern than its position relative to all nations as examined previously. Australia ranked most highly in Year 8 Mathematics within TIMSS, coming in 10th out of the 24 nations identified in the OCS report. This is in stark contrast to performance in the Mathematical Literacy component of PISA where Australia placed 19th. The remaining domains of each test saw Australia place consistently between 11th and 15th. Thus, compared with these 24 'competitor' nations, Australia's performance in STEM by the metrics of PISA and TIMSS leaves much room for improvement. However, the validity and reliability of using PISA and TIMSS as means of determining students' STEM skills is yet to be determined.

Reasoning with PISA and TIMSS data

Feniger and Lefstein (2014), in an investigation regarding conclusions which can be drawn from PISA data, highlighted two assumptions which are typically used in its analysis. The first is the Policy and Structures Assumption, which assumes that a nation's approach to education underlies its PISA performance. There is reason to question whether or not this assumption is valid in light of the fact that despite decades of educational investment aimed at improving performance in standardised tests such as these, little gain is typically observed in students' performances, with many in fact showing a decline over time (Redman, 2017). Indeed, "enduring changes in education practice take decades, not a few years, to come to fruition" (Andrews et al., 2014, para. 4) and so the quick fixes that are often applied in an attempt to climb the rankings are unlikely to result in rapid improvement. Are these educational interventions having impact on students' performance and, if so, are PISA and TIMSS the right tools to use to determine if any impact is being had? After all, it would appear possible that a greater focus on problem-based or inquiry learning may improve students' problem-solving abilities within real-life problem solving and that this may not be detected within a standardised test.

The second, the Cultural-Historical Assumption, assumes that social, economic and cultural values are the main source of variation in student performance. To examine the possible impact of factors under the Cultural-Historical Assumption, Feniger and Lefstein (2014) conducted a study to investigate the PISA performance of students of Chinese origin living in Australia and New Zealand and found the results from each country to be not statistically significantly different from students from Shanghai[7]. However, non-Chinese Australian students performed at a level that lay a full standard deviation below their peers of Chinese origin. A similar trend was observed in New Zealand, albeit to a lesser extent, with approximately 60% of a standard deviation. As a result Feniger and Lefstein (2014) propose that

> While it may be politically attractive and expedient to attempt to imitate the educational policies and structures of high attaining systems, our analysis reinforces the argument that such cross-national policy borrowing will be ineffective without attending to the historical and cultural contexts in which those policies operate (p. 850).

Thus, while the publication of rank orders allows for easy comparisons to be made regarding where a nation places relative to other nations each year and its own performance from prior years, as was done in the preceding analysis, one must be careful regarding the conclusions that are drawn.

Another issue with the commonly used methods of reporting is that statement of the overall average performance alone does not give insights into how various demographics performed, or the

[7] Feniger and Lefstein (2014) could not compare with China as a whole as different regions are listed separately within PISA. Similarly, data collection in Australia and New Zealand did not provide information on the region of China students came from, just 'China', thus direct regional comparisons could not be made.

distribution of skill levels or the proportion of students performing at a high level. In other words, very limited information is of use when average results alone are stated. The league tables that are published rank countries based upon their average scores, not the proportion of highly-performing students or other statistics which might provide more useful insights (Salzman & Benderley, 2019). While ACER releases detailed reports on Australia's results, including analysis by state/territory, sector and so on, the media generally only reports averages.

It is also necessary to consider the extent to which these standardised international tests examine what they set out to, and what a country is actually interested in knowing regarding the performance of their students. PISA aims to be a literacy test, designed to examine the extent to which 15 year old students "are prepared to use the knowledge and skills in particular areas to meet real-life opportunities and challenges" (S. Thomson, De Bortoli, et al., 2016, p. xi). The test is composed of a number of tasks with lengthy text-based descriptions followed by a number of questions, for which both multiple-choice and open-response types are included. The content of these tasks has less to do with specific academic content than it does general world knowledge, the type that may be learnt at school but would also be acquired outside of school. TIMSS is quite different in that tasks are much shorter with little scenario-setting text and are quite closely aligned with curricular content (Rindermann & Baumeister, 2015). However, while the results of these tests are often used by policy makers, there are examples in the literature of studies which question the validity of interpretations of PISA and TIMSS. For example, Rindermann and Baumeister (2015) question the extent to which PISA and TIMSS tasks measure the declared target ability. Furthermore, Roehl (2015) suggests that the inclusion of 'little scientists' as characters with whom students are to engage when solving the 'real-world problems' which feature in PISA tasks can lead students to reject the imaginary roles in which they are placed, create resistance to the test questions, and thus interfere in their problem-solving process.

Finally, while TIMSS is administered by the IEA, which has a clear mandate for involvement in educational assessment, PISA is organised by the OECD, which has no such educational mandate. Following the 2012 round of testing, over 80 academics from around the world penned an open letter to Dr Andreas Schleicher, Director of PISA, in which they expressed their views on the negative impacts of PISA testing,

> We assume that OECD's Pisa experts are motivated by a sincere desire to improve education. But we fail to understand how your organisation has become the global arbiter of the means and ends of education around the world. OECD's narrow focus on standardised testing risks turning learning into drudgery and killing the joy of learning. As Pisa has led many governments into an international competition for higher test scores, OECD has assumed the power to shape education policy around the world, with no debate about the necessity or limitations of OECD's goals. We are deeply concerned that measuring a great diversity of

> educational traditions and cultures using a single, narrow, biased yardstick could, in the end, do irreparable harm to our schools and our students (Andrews et al., 2014, p. para. 23).

This is a scathing indictment, which ought to serve as a caution to those responsible for educational policy in participating countries to not put too much stock in PISA results, and certainly not in the league tables through which average performance is reported.

Reasoning with PISA and TIMSS data is not a straight-forward exercise, one must be clear about what the tests set out to assess as well as the extent to which certain tasks assess particular competencies. Whilst the OCS (2014a) used these tests in their *Benchmarking* paper as a key metric for how schools were performing in STEM, it has not been ascertained that the skills required for success in STEM are the same as those as tested by PISA and TIMSS. While the two tests cover science and mathematics, two components of STEM, they have relatively little direct connection to technology and engineering, or STEM in its integrated sense. TIMSS assesses knowledge and skills in science and mathematics and PISA assess scientific and mathematical literacy, but they do so in a siloed manner. If STEM education is more than science + technology + engineering + mathematics (Bybee, 2016; Herschbach, 2011), and STEM literacy is more than scientific literacy + technological literacy + engineering literacy + mathematical literacy (Bybee, 2016; Yore et al., 2007; Zollman, 2012), then it must be questioned whether standardised tests which focus only on the S and M of STEM, in isolation from each other, can really be considered to be an appropriate metric for determining the STEM competencies of students. Indeed, it has been said that

> The relationship between test scores and innovation or other aspects of STEM development is noticeably weak by any direct measure. Moreover, the metrics do not reflect the outcome of school characteristics or performance, per se, and the metrics themselves are, at best, of an unknown relationship to economic and innovation outcomes (Salzman & Benderley, 2019, p. 21).

An important question this study will therefore seek to answer is the extent to which PISA and TIMSS are appropriate metrics for assessing Australian school students' STEM skills. Chapter 7 will explore the PISA and TIMSS frameworks, with a particular focus on the skills they are designed to test, to see the extent to which these overlap with STEM skills found in the literature and articulated in Chapter 5.

Conclusions on the educational argument

There is a wealth of evidence to show that Australian school students' performance within key international tests such as PISA and TIMSS is declining and that Australia does not rank highly among the countries chosen by the OCS (2014b) for comparison in its *Benchmarking* paper. However, Australia remains significantly higher than the OECD average and there are relatively high proportions of top performing students in each of the tests. Thus, there is consistently a proportion of Australian students who perform very strongly. Unfortunately, this is balanced with a large proportion of students at the low end of the proficiency scale. It is arguably the gap between the top and bottom performers which warrants greater attention than the average performance of Australian students.

However, it remains to be determined just how valid and reliable a tool these tests are for assessing STEM skills specifically. Increasing STEM literacy and skill development during schooling would seem to be a worthwhile endeavour by way of bettering not just the future STEM workforce but the STEM literacy of all citizens. A focus on STEM skills in schools is warranted, not so much due to Australia's lacklustre performance in international tests, but by way of understanding the current STEM skill level of Australian students and how to improve it in the future. If we are to continue using these metrics as a way of gauging Australian students' performance in STEM relative to either 'like' nations, or the world more broadly, it is vital that what they assess and thus what conclusions can be made about the results are clear. This will be ascertained via the third research question of this study, the results and analysis of which may be found in Chapter 7.

The STEM workforce argument

While not a new argument, one commonly cited by governments for the increased focus on STEM is related to its strong links to innovation, which in turn is linked to maintaining a strong economy and global competitiveness (ACOLA Secretariat Ltd, 2016; Waite & McDonald, 2019). STEM-qualified workers are required for approximately 75% of the fastest-growing occupations in Australia and thus the demand for STEM workers is likely to continue to increase (Chapman & Vivian, 2017). As a result of the huge growth in the STEM sector, the potential for a STEM shortfall of thousands or even millions of workers has created something of a panic across the world, with reports coming out of a diverse range of nations. Reports on this issue are coming out of Australia and all major regions of the world (Charette, 2013). Thus, billions of dollars every year are being directed at efforts to boost the number of STEM workers, whether it be through training more people, adjusting immigration legislation to bring in more skilled workers (as is done by the US and European Union), or the creation of more universities. Governments everywhere are scrambling to address the STEM shortfall (Charette, 2013). As a STEM qualification typically relies on a firm grounding in STEM at high school, much focus is being placed on STEM K-12 education (Berry, Chalmers, & Chandra, 2012; Blackley & Howell, 2015; Bybee, 2016). This further supports the contention that STEM skills that STEM employers desire in their employees need to be identified and developed during the high school years.

However, while there is the aforementioned abundance of reports of a global STEM worker shortfall, there are also many reports of STEM graduates unable to find full-time work upon graduation (Henebery, 2019; Panizzon, Corrigan, Forgasz, & Hopkins, 2015; Tonkin, 2019). This has led to the rather odd situation of STEM employers being unable to find suitable workers at the same time that STEM-trained graduates are unable to find work. This issue is prominent in many countries and has become known as the global STEM paradox (Kramer et al., 2015). Whilst this is a global issue, the nature of the contributing factors to this paradox will be considered here from an Australian perspective.

Australia's growing STEM sector

Reports produced by organisations such as the Australian Academy of Science (2019), the Australian Industry Group (2015, 2017) and ACOLA (2016), the OCS (2013a, 2017), and by the Australian Government Department for Education, Skills and Employment (2019b) and the Department of Industry and Science (2015) have consistently argued that a focus on STEM is vital for Australia's international competitiveness. This has been demonstrated via growth of 16.5% in the STEM job sector from 2013 and 2018. That is a rate 1.6 times higher than the growth rate observed in non-STEM job sector over the same time period (Deparment of Education, Skills and Employment, 2019b). This growth rate is expected to continue over the next decade with at least with 53% of businesses and industry expecting their need for STEM-workers to grow (Chapman & Vivian, 2017). However, an odd paradox has developed in which employers claim that there is a significant shortfall of appropriately STEM-qualified workers (Chapman & Vivian, 2017), with up to 75% of employers being unable to recruit appropriately qualified workers. Yet at the same time, STEM-graduates are struggling to find work within the STEM sector (Henebery, 2019). This section aims to explore some of the reasons for this paradox.

Australian STEM graduates

Despite the growth in STEM jobs, there is a long history within Australia of STEM-trained students finding it difficult to obtain employment within the STEM sector upon graduation (Birrell, 2014; Panizzon et al., 2015). The Graduate Destination Surveys completed by Australian university graduates within four months of completing their course from 1999-2009 found that graduates with a major in a STEM field often ended up working in a field unrelated to their degrees. Furthermore, those who did find employment within the STEM sector were earning less than their non-STEM employed peers (Panizzon et al., 2015). The problem is only getting worse, with lower proportions of STEM graduates being able to obtain work in 2014 compared with 2008, as shown in Table 4.

Table 4 – Proportion of STEM-graduates able to find work in 2008 vs. 2014 (Birrell, 2014)

Discipline	2008	2014
Engineering	90%	75%
Life sciences	76%	48%
Physical sciences	85%	55%
Computer science	83%	67%

As shown in Table 4, all of these areas of STEM saw a lower proportion of graduates finding work over time despite the increasing rhetoric around job growth within these fields (Birrell, 2014). In terms of science graduates more recently, the 2016 Grattan Institute's *Mapping Australian higher education* study indicated that only 51% succeeded in finding full-time work in 2015 four months after completing their course. Furthermore, of those who did find work, only half said that their qualification was required or important (Norton, 2016). This led the Higher Education Program Director of the Grattan Institute, Andrew Norton, to indicate that "we are in uncharted territory" and that he is "very nervous for the career prospects of recent science graduates" (Knott, 2016a, para. 11). Science degrees were once seen as a pathway to many possible careers and a degree that would encompass the development of valuable skills applicable to a range of professions. However, the lack of success graduates are having in securing jobs means that students may need to reconsider their degree if they wish to gain employment upon graduation (Norton, 2016).

The reality of the difficulty of STEM graduates to find work has perhaps contributed to the drop in the proportion of Australians obtaining a STEM qualification in the decade from 2008 to 2018. In terms of the proportion of people aged 20 to 64 working in STEM fields relative to the population as a whole, this number dropped from 46% to 43% for men and from 10% to 9% for women over the same time period (Scutt, 2018).

While the worker shortage argument is typically made with a focus on graduates, it is important to also investigate how the experienced workforce is faring (Harris, 2014). The attrition rate over the course of an individual's career is higher within STEM occupations than in many others. This issue is compounded by the fact that, unlike professions that see an intake of mature recruits to help balance the loss of workers during their career, very few people move into STEM from a non-STEM field. A key contributing factor to this issue is likely to be the relatively short period of time within which a STEM degree can be considered to be 'in date' as most STEM disciplines progress at a rapid rate (E. Smith & White, 2019).

Challenges facing STEM-qualified workers

The notion of a STEM-worker shortfall, despite STEM-qualified workers being unable to find jobs within STEM, is a paradox that is by no means unique to Australia (Charette, 2013; Kramer et al., 2015; Marginson et al., 2013). A number of factors has been identified as contributing to this ongoing paradox, namely: competition with skilled migrants; spot shortages; insufficient attention being placed on the importance of the vocational education and training sector; underrepresentation of specific groups within STEM; and a lack of the skills employers want within the STEM-qualified employee pool (Harris, 2014; Kramer et al., 2015). Each of these factors will now be considered.

Competition with skilled migrants. A key factor which contributes to the struggle for Australians to obtain a job within STEM, whether they be graduates or experienced workers, is competition with skilled migrants (Kramer et al., 2015). These migrants may have entered Australia through the permanent entry skilled migrant program or are 457 visa holders who have been sponsored for temporary work by employers. There is also competition from overseas students who study in Australia and then obtain work through the Temporary Graduate visa or qualified workers on temporary visas with work rights (Birrell, 2014; Kramer et al., 2015). This is a particular problem for Australian Information Technology (IT) graduates as they are dwarfed in numbers when compared with the number of migrants applying for permanent or temporary skilled visa problems to work within the IT sector (Birrell, 2014). A study by the Grattan Institute showed that a third of 2015's Australian IT graduates could not find full-time work (Norton, 2016). However, it is not just within Science and IT that this is problematic. For the past one to two decades, a dominant source of Australia's engineers has been skilled migrants. This is particularly difficult for Australian engineering graduates as Australia's skilled migration policies are aimed at workers with entry-level qualifications rather than securing workers who are experienced engineers (Kaspura, 2017). It seems that Australian workers trained in mathematics fare best at the moment as there are signs of gaps within the workforce such as higher salaries and vacancy rates (Panizzon et al., 2015).

Spot shortages as opposed to whole of STEM shortages. It is important to remember that STEM is a very heterogeneous collection of occupations and thus it is possible that there is an oversupply in some areas and an undersupply in others (Hira, 2019; E. Smith & White, 2019). Therefore, while there is some evidence to suggest that there is a genuine shortfall of workers, it is not necessarily as widespread as it is generally made out to be by policymakers (Harris, 2014). Much is said regarding the need for STEM workers, with no qualifier as to exactly what type of STEM worker is needed. The problem perhaps is not that there are not enough workers across the whole of STEM, but rather that there are spot shortages in specific areas within STEM (Harris, 2014). The problem with spot shortages is that they are not static, they get filled over time and spot shortages in other areas develop. Thus it is unwise to advise high school and university students to focus on training to become able to fill shortages that exist today as shortages will in all likelihood be in another area entirely by the time those students graduate (Camilli & Hira, 2019; Charette, 2013).

Too much of a focus on the tertiary sector at the expense of the vocational education and training sector. Further complicating the problem in Australia is that, while there is a continual call for students to consider going into STEM, many are overqualified due to a disproportionate focus upon university qualifications (Kramer et al., 2015; Marginson et al., 2013). The *Australian Standard Classification of Education, 2001* identified STEM qualifications to include "Postgraduate degree level, Masters degree level, Graduate diploma and Graduate certificate level, Bachelor degree level, Advanced diploma level, and Certificates II to IV levels in any of the fields below:

- Natural and physical sciences (NPS) (including Mathematical Sciences)
- Information Technology (IT)
- Engineering and Related Technologies (RET)
- Agricultural, Environmental and Related Studies (AERS) (Soriano & Abello, 2015, p. 347).

Thus, careers within the health sector are not classified by these criteria as pertaining to STEM. This is just one demonstration of the multiple interpretations of what is deemed to be a STEM qualification as the health sector is included within some other definitions (Marginson et al., 2013). The key point though is that a STEM qualification does not necessarily mean a degree.

Within Australia the rhetoric often overlooks the fact that STEM tertiary education encompasses not just universities but also the Vocational Education and Training (VET) sector. In 2010, the higher education sector catered for 861,500 Equivalent Full Time (EFT) students, with 349,000 EFT students in STEM disciplines, accounting for 32.7% of higher education enrolments. Meanwhile the VET sector had 655,800 EFT students, with 195,000 EFT students, or 29.9% of enrolments, within STEM (Marginson et al., 2013). Furthermore, Australia's STEM workforce comprises approximately 2.3 million people, of whom only 32% are university qualified, the rest obtained their training from the VET sector (Baranyai et al., 2016). Thus, while a greater number of students study STEM at university than in the VET sector, they do not form the majority of the STEM workforce. This contributes to the issue of employers unable to hire and employees unable to secure a job. Much of the employee pool does not have the skills and training the majority of employers in the STEM sector require.

Further complicating the issue, the Australian Government has recently released a policy to overhaul university fees as of 2021. This will see a decrease in fees for STEM degrees by up to 62%

and an increase in fees for degrees such as law and commerce (28%) and the humanities (113%) (Duffy, 2020). The purpose of this is to make degrees in fields of study where job opportunities are expected to grow (predominantly STEM) cheaper to encourage more people to enrol in these degrees. Ironically, this is designed to increase the graduate employment rate (Duffy, 2020) which is high due to the challenges faced by STEM graduates, not due to there being an insufficient number of graduates. The only mention of the vocational sector is that there is a lower unemployment rate for those graduates (Duffy, 2020) with no reference to the fact that it is the VET sector that employs the majority of Australia's STEM workers (Baranyai et al., 2016). This policy change reinforces the emphasis on university rather than vocational education and, rather than increasing the rate of graduate employment, would appear to actually decrease it further by adding more graduates to the pool of people who are already unable to secure a job within STEM.

Underrepresentation of women. Another factor that perpetuates the paradox is the consistent underrepresentation of women, minorities and other marginalised groups within STEM (Kramer et al., 2015). Within Australia, the focus regarding this issue is predominantly focused upon the lack of a gender balance and the need to get more women into STEM.

Gender differences are apparent within STEM as early in Years 9 and 10 when students start selecting the electives they wish to study. Recent research into Australia's youth in STEM highlighted this gender skew in secondary education and how it flowed into tertiary education:

Table 5 – Proportion of male versus female participation in STEM in high school and higher education (Youth Insight, 2019)

	Males (%)	**Females (%)**
Studying at least one STEM elective in Years 9 and 10	70	32
Studying at least one STEM elective in Years 11 and 12	99	91
Contribution to the 26% of higher education students studying a STEM related course	35	18
Considering taking at least one STEM course as part of their higher education	58	36

Table 5 shows that, across the board, women were less likely to choose to study STEM. The difference between males and females is less pronounced for the second row, viz.: studying at least one STEM elective in Years 11 and 12. This is likely to be due to mathematics being either compulsory, or strongly encouraged, in all jurisdictions.

It is not just in the proportion of students participating within STEM that there is a skew towards males. Males were found to have: more favourable attitudes towards STEM subjects (especially towards engineering and technology); a higher interest level in STEM subjects; and greater confidence in achieving results in engineering and technology (females had similar confidence levels to males for mathematics and science) (Youth Insight, 2019). The difference in confidence level towards STEM between males and females has been found to exist as early as Year 4 (Department of Industry, Science, Energy and Resources, 2019). These issues at the start of the STEM pipeline are perpetuated from then on. A range of examples that demonstrate Australia's issue with a lack of women in STEM are listed below (Australian Academy of Science, 2019):

- Performance in numeracy in NAPLAN[8] is skewed towards males as early as from Year 3 (the first year of testing);
- Half as many female students aspire to a STEM-related career;
- Completion of STEM education at the tertiary level is far lower for women;
- Females are under-represented in STEM within the university as well as the VET sectors;
- Women are underrepresented among STEM academics;
- There is underrepresentation of women in the STEM workforce, within engineering and IT in particular;
- Women have lower incomes than men in engineering, IT and science.

There are issues for women at every step along the STEM pipeline, which is perhaps to be expected given that there is a gender disparity at least as early as Year 3 in terms of numeracy skills and Year 4 in terms of confidence levels (Australian Academy of Science, 2019). The huge differences seen within STEM between males and females is not unique to Australia. However, it does contribute to the apparent lack of STEM workers in that we are not maximising our capacity to draw on the knowledge and skills of half of the population. Women in STEM has been an issue for at least the past two decades as their participation has not changed substantially in that time (Chapman & Vivian, 2017). There are many efforts to address the lack women in STEM from the Australian Government down (Department of Industry, Science, Energy and Resources, 2019). It must be remembered, however, that this is just one of the contributing factors to Australia's STEM workforce problem.

It is not a STEM qualification per se, but rather STEM skills, that are lacking

Clearly there are many issues that contribute to why STEM qualified Australians struggle to find jobs within the STEM sector, even though STEM employers say they cannot find suitable

[8] NAPLAN is the National Assessment Program for Literacy and Numeracy, it is administered nationwide annually for students in Years 3, 5, 7 and 9.

employees. Perhaps the biggest contributing factor to this issue lies at the heart of this study, and that is the mismatch between the skills Australians are developing during their education and the skills their employers desire in their employees. Scutt (2018) went so far as to say

> that [lack of skills'] may partially explain why Australian businesses are now reporting skill shortages well above the average level seen since the turn of the millennium.
> Australians, in a broader sense, may not actually be learning the skills that are required now and in the future (para. 8 and 9).

The Australian Academy of Science (2019) claims that "STEM skills are the foundation on which the Australian workforce, industries and the economy will thrive and prosper" (p. 10). They also note that the line between what has been seen as a STEM job versus a non-STEM job is not as clear as it once was given the centrality of technology to today's economy (Australian Academy of Science, 2019). Similarly, within the US, Carnevale, Smith, and Melton (2011) found that people with a strong STEM skill set were able to divert into non-STEM occupations with relative ease. This indicates that STEM skills are desired across the workforce. Carnevale et al. (2011) concluded "that our [US] education system is not producing enough STEM-capable students to keep up with demand both in traditional STEM occupations and other sectors across the economy that demand similar competencies" (p.10). Such an argument would help to explain why countries such as the US and Australia, which are producing many STEM graduates, still have employee shortages in some areas. These graduates are not just prepared for a career in STEM, they have a range of attractive transferable skills and abilities that enable them to work in a wide range of other sectors. An acknowledgement that STEM skills are useful, not just within traditional STEM areas, but also more broadly, suggests that if there is any shortage, it is in fact in STEM skills across the workforce (Marginson et al., 2013). In light of the diversity of sectors in which these skills are lacking, putting a focus on the development of STEM skills while future workers are still in secondary school is warranted.

The Australian Industry Group (2018) conducted a Workforce Development Needs Survey. The results indicated that three quarters of respondents (employers) were experiencing skill shortages, particularly within the technician and trades worker category. Basic skills such as literacy and numeracy, along with digital skills and the ability to lead a team and to manage projects were all identified as lacking within the potential-employee pool (Australian Industry Group, 2015). Even within the IT sector, which is generally thought to have a predominant focus upon IT-specific skills, it is being recognised that what is often lacking are a variety of soft skills, such as communication and collaboration (Tonkin, 2019). This is because niche skills that make someone an expert in the technology of today are not necessarily transferable to the niche skills required to succeed in the technology of tomorrow. Thus, while technical skills are still required across STEM disciplines, there is a much broader range of more transferable skills that employers are looking for as these skills will allow their employees to succeed in the long-term (Australian Industry Group, 2018; Tonkin, 2019).

An example of the range of skill types required and their current relative supply and demand is shown in Figure 5.

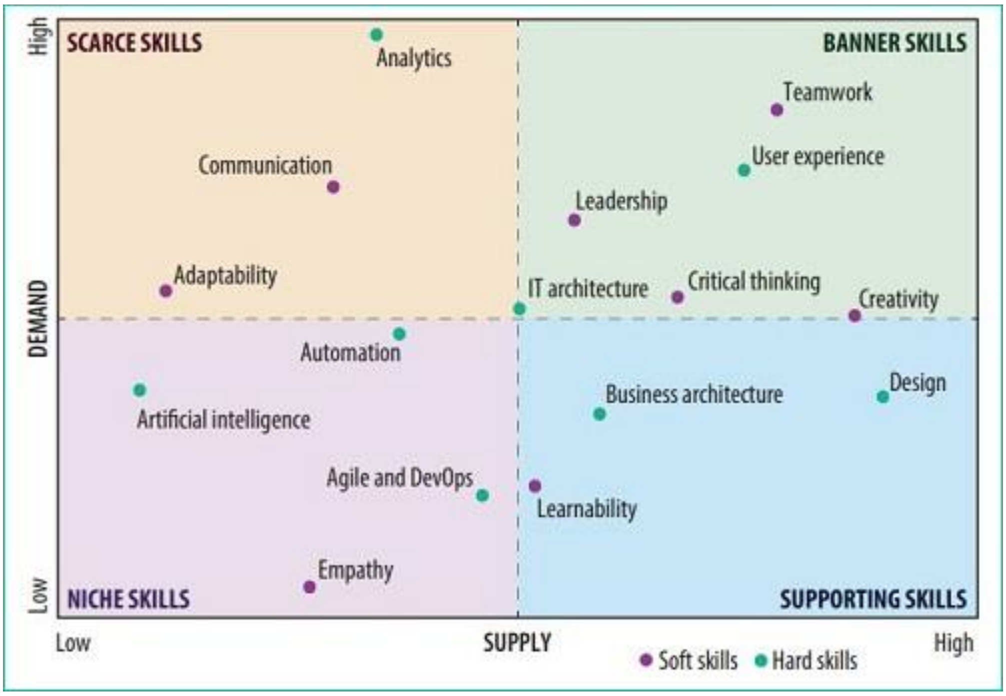

Figure 5 – Skills priority and scarcity within the IT sector (Tonkin, 2019)

Figure 5 shows that while a range of specific hard skills are valued, a wide variety of soft skills is equally as important and can be difficult to find.

Thus, while there are many factors which contribute to the STEM worker paradox, one aspect that has not been explored in as much detail until relatively recently is the notion of the specific STEM skills for which employers are looking. Unfortunately, despite the increasing discussion of STEM skills and their importance, very few sources give a clear indication of exactly what these skills are assumed to be. The articulation by Tonkin (2019) as shown within Figure 5 is unique in terms of the detail provided, though this is just from one source, and an IT-specific one at that.

Conclusions on the workforce argument

The apparent paradox of STEM employers being unable to find workers and STEM graduates being unable to find work is not unique to Australia but is a problem that Australia needs to address if it is to remain competitive worldwide (Marginson et al., 2013). Despite strong growth within the STEM sector, Australian STEM graduates as a proportion of all graduates is in decline, and those who do graduate find it difficult to secure full time work within the STEM sector. There are some contributing factors to this problem: such as competition with skilled migrants; the prevalence of spot shortages rather than the typically advertised whole of STEM shortages; a neglect of the VET sector; and the underutilisation of half of the population, with a gender skew towards males being evident as early as primary school. However, perhaps the biggest issue is that STEM graduates lack the specific skills desired by the workforce. It is not just specific knowledge but skills that are desired by employers across the board, regardless of whether they seek to employ university graduates or those from the VET sector (Australian Industry Group, 2017). Whilst the issue of skills is being discussed to an increasing degree, the description often stops at a desire for STEM skills, with no articulation of what these may be. If a large-scale shift in the number of people entering the workforce with these skills is to occur, the desired skills must be clearly articulated and developed from as early an age as possible.

Regardless of the position various stakeholders take on whether or not there is a STEM shortage, there is general agreement that the workforce "market for STEM skills is changing rapidly, and STEM education should be sensitive to new developments" (Camilli & Hira, 2019, p. 3). Therefore, the most worthwhile place to put a focus, within a high school context in particular, is upon STEM *skills* as these will be able to be applied within a wide range of occupations and are transferable from one occupation to another.

Counterarguments for a focus on STEM in Education

Before concluding this chapter, it is important to acknowledge some of the concerns expressed in the literature regarding the strong focus on STEM in education today. Cautionary papers are very rare but not non-existent when it comes to STEM education. Hill (2019) and Zhao (2019) provide recent examples of what they see as being the dangers of a focus on STEM within K-12 education within the US; Australian equivalents were unable to be found. While they both make some pertinent points, they appear to be operating under an assumption that STEM is overemphasised in K-12 education at the expense of other areas of education. While it is unclear what recent experience either have within K-12 education, and of what schools and programs they are so critical, the situation they describe is at odds with the author's experience of K-12 education in Australia. However, first to focus upon their key arguments.

Hill (2019) argues that 'STEM is not enough'. This is not only true, but it is also the perspective of most people within STEM education. While STEM is seen as being very important in terms of the increase in the future job market of the proportion of jobs requiring STEM knowledge and skills, STEM advocates do not propose STEM *alone* is the answer. The ability to read and write, to communicate, to empathise, to be able to socialise with people who have similar as well as different backgrounds to themselves, and to have skills and interests beyond STEM are of great importance. Hill (2019) states that,

> We need to put aside the notion that we should strengthen STEM education at the K-12 level as if we were preparing everyone to become the next generation of scientists; instead, we should do it in a way that prepares every student for their own work, life, and citizenship" (p. 73).

This statement conflates science with STEM by suggesting that the aim is to produce scientists with no mention of technologists, engineers or mathematicians, let alone those people who will end up in professions that are neither science, technology, engineering nor mathematics but lie at the more common nexus of two or more of these disciplines. Its premise that STEM education seeks to prepare *everyone* to be a scientist, or even *everyone* to work within a STEM field is not valid. While the argument is often made that STEM is of importance in that many future jobs will require knowledge and skills in this area, it would be absurd to suggest that all students will end up in a STEM field. However, what is important to recognise is that our world is increasingly technological and that to be a well-informed citizen, capable of making evidence-based decisions and contributing positively to society, STEM literacy is of increasing importance for everyone, regardless of the profession they pursue (Bybee, 2016). Furthermore, STEM-qualified individuals are often found working outside of STEM fields, indicating that skills developed within STEM education are valued by the workforce as a whole (Carnevale et al., 2011).

Zhao (2019) discusses the rise of what he terms ‘useless’ talents such as the performing arts and taking care of animals and people. He argues that with an increasing need for diversity of talents, the increasing ability for people to pursue non-essential needs, and the increasing globalisation of today’s world, a range of talents formally seen to be ‘useless’ are of increasing benefit. However, this begs the question of when and by whom were these talents deemed to be ‘useless’? While the performing arts pay on the whole better than they perhaps used to, musical prowess and ‘caring’ professions such as nursing have long been admired and valued. Zhao (2019) is correct in his assertion that diversity in talent is needed for economic prosperity, but he does so in a manner which suggests a limited understanding of the K-12 education environment,

> … formal education, in the form of schooling, is designed to cultivate valuable and desirable capabilities and suppress useless and undesirable qualities... Schools have been focussing on supporting only a small range of qualities and favour only certain types of individuals while suppressing, or neglecting, a larger part of the diverse talents. In other words, what is valued and taught in schools today is already very narrow. The efforts to elevate the status of STEM subjects can only further narrow the spectrum of talents considered worth cultivating.
> If K-12 schools move further away from a broad curriculum and toward more STEM subjects, children will be deprived of the opportunities to even discover their interests and talents (p. 66).

While STEM is the latest ‘thing’ in education, it is by no means all that schools are teaching. It may be true to suggest that formal education places a higher value upon academic pursuits, but these are not limited to STEM; achievements in English and the Humanities are valued highly too. Schools have sporting carnivals and events to cultivate and celebrate their students’ sporting abilities. Most schools offer music, drama, visual arts and a range of other ‘creative’ subjects for which students can win awards, just as they would in a more ‘academic’ subject. In the case of Australia at least, it is possible to excel in creative subjects and attain an ATAR[9] that is just as high as someone who studied the highest level of mathematics along with chemistry and physics in Year 11 and 12. To suggest that schools have a 'narrow curriculum' is a gross understatement of what modern education encompasses. In Australia, high school students (Years 7-10) typically study up to eight subjects and are also taught an array of things that used to be done by parents at home but has since fallen to teachers in schools. Cries of an overcrowded curriculum are much more prevalent (Department of Education, 2014; Hunter, 2018).

Both Hill (2019) and Zhao (2019) acknowledge the importance of STEM and an understanding of why it is a focus area in K-12 education at present, though both seem to have overestimated the degree of focus on STEM that is actually lived out schools. Yes, there is an abundance in the literature regarding the importance of STEM education, and it is an area of focus for many schools. However, schools remain institutions dedicated to learning in all forms, and the majority of teachers strive to help their students to achieve their best in all their endeavours and to pursue their aspirations.

Summary of Chapter 3

An educational and a workforce argument have been presented regarding the importance of STEM education. As STEM is seen as being important for a country's competitiveness and STEM literacy is seen as being important for all citizens, there is a strong argument for a focus on STEM during primary and secondary education. Metrics such as PISA and TIMSS are commonly used to keep track of how Australian students are performing in STEM over time, as well as how they compare with other students. Perceptions regarding a decline in the skill level of Australian students are a strong imperative for the continued national focus on STEM and STEM skills. However, while Australian students' results in these tests are in a decline, it is yet to be established whether these tests are appropriate metrics for making comments regarding students' STEM skills.

The other key argument for the focus on STEM pertains to the workforce. This argument is a little harder to pin down as, while there are general claims regarding a STEM worker shortage, there is evidence to suggest an oversupply. What is clear is that the job market, particularly within STEM, changes rapidly and so students must be prepared to join a workforce that will be different from that of today. Furthermore, employers are making it increasingly clear that it is skills, rather than knowledge, that they desire among their employees. Given the general applicability of many STEM skills to jobs in and outside of STEM a focus on the development of these skills is justified, regardless of whether there is in fact a specific type of job shortage.

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[9] An ATAR is an Australian Tertiary Admission Rank. Universities set minimum ATAR requirements for their undergraduate degrees.

However, for teachers to support their students in the development of STEM skills, we must first be clear about what we mean by STEM skills. Second, once this set of skills is identified, the support inherent within the Australian Curriculum for the development of these skills needs to be determined Finally, the efficacy of PISA and TIMSS in the assessment of these skills must be determined. Without answers to these questions, Australian teachers are unable to ensure that their students are equipped with the skills they need to succeed in the workforce of today and tomorrow. Chapter 4 outlines the methods used to investigate these three components which together enable conclusions to be drawn regarding how to help Australian high school teachers to develop and assess the STEM skills their students will require to succeed in the workforce.

Chapter 4 – Methodology

Introduction

The literature review presented in Chapters 2 and 3 indicates the central importance of STEM skills in today's economy both within and beyond the STEM workforce. However, it is also apparent that despite government and industry frequently emphasising the importance of STEM skills, a clear list of what these skills are is lacking. The Australian Curriculum covers STEM through the learning areas of Mathematics, Science and the Technologies. It also has a focus on skills through its general capabilities and the cross-curriculum priorities. However, the extent to which the STEM skills wanted by employers are highlighted within the curriculum is not known. Finally, while PISA and TIMSS results suggest that Australian students perform poorly relative to their international peers, the extent to which these tests measure STEM skills is unknown. This raises the question of the reliability and validity of these tests for gaining insight into Australian students STEM skills. By way of contributing to the national conversation regarding Australian students' STEM skills, this study sought to determine how to develop and assess the STEM skills Australian students need to be successful in the modern workforce.

To address this overarching question, the following research questions were investigated:

1. What are STEM skills?
    - 1a. What are STEM skills according to the literature[10]?
    - 1b. What are STEM skills according to Australian Year 7-10 STEM teachers?
    - 1c. How do the perspectives on STEM skills from the literature and from Australian Year 7-10 STEM teachers compare?
2. To what extent does the Australian Curriculum support the development of STEM skills?
    - 2a. What skills are made explicit in the general capabilities, cross-curriculum priorities and the STEM learning areas of the Australian Curriculum?
    - 2b. To what extent do Australian Year 7-10 STEM teachers feel the Australian Curriculum supports them in developing STEM skills in their students?
3. To what extent do PISA and TIMSS assess these skills?

The details of how each of these questions were examined are presented in turn.

[10] Please note that throughout, 'literature' pertains not only to the conventional literature, but also to governmental and industry reports as explicit discussion of STEM skills is far more prevalent in these reports than in the conventional literature.

Research Question 1 – What are STEM skills?

Introduction

For high school teachers to assist their students to develop the STEM skills they will require to succeed in today's workforce, it is vital to define what is meant by the phrase 'STEM skills'. As there is no universally agreed upon definition, a list of skills meant by the phrase had to be determined. In Research Question 1a, a view on what the literature suggests STEM skills to be was developed from an examination of a range of reports that clearly articulated skills related to STEM jobs. General employability skills were also considered due to the lack of soft-skills noted by STEM employers (Tonkin, 2019) and that the STEM sector is very broad, therefore a range of generic employability skills will be required by STEM and non-STEM workers alike. These documents were focused upon skills for the workforce but were read through the lens of which skills were suitable for development within a high school context by the author, who has over a decade of experience of working in Australian high schools. This analysis led to the construction of five overarching domains of STEM skills with examples of associated skills for each domain. In Research Question 1b, Australian high school teachers were asked to identify what they thought STEM skills were via a survey. Finally, in Research Question 1c, the skills identified within the literature and those identified by teachers were compared by way of seeing whether the STEM skills desired by the workforce are the ones teachers think their students need. Greater detail on how parts 1a to 1c were carried out will now be provided.

Research Question 1a – What are STEM skills according to the literature?

In examining the literature, it was observed that the conventional literature makes very little reference to the specific types of skills meant by the phrase STEM skills. Additionally, while many governmental and industry reports make reference to STEM skills, they either: failed to provide any examples of such skills (Australian Industry Group, 2013; Office of the Chief Scientist (OCS), 2013a); referred broadly to problem-solving, critical thinking and creativity (Baranyai et al., 2016; OCS, 2014a); or added slightly more detail, including specialist STEM skills (no actual definition of what these may comprise), quantitative skills, open-mindedness, logical thinking and literacy and numeracy skills (ACOLA Secretariat Ltd, 2016; OCS, 2014b). While teachers within STEM would no doubt agree that such skills can be developed within STEM subjects at school, teachers from almost all other subject areas could argue that their subject enables the development of many of these skills too, especially skills such as creativity, critical thinking and problem-solving. So, is it a specific form of each of these skills which STEM seeks to provide, or is it that STEM leads to a greater development of these skills than non-STEM subjects? As a key aim of education is to prepare students with the skills they need to contribute to the workforce, it is prudent to consider the skills STEM employers want and to work backwards from there in order to answer these questions.

Four reports were chosen for this analysis as they were found to explicitly outline a range of skills, though it must be noted that these reports have not been through the peer review process. In 2016 the OCS released a report titled *STEM skills in the workforce: what do employers want?* (Prinsley & Baranyai, 2015). This report was based upon a survey commissioned by the OCS and conducted by Deloitte Access Economics (DAE, 2014) in which employers were asked questions about a list of thirteen skills. Given the name of the report, these thirteen skills were presumably deemed to be STEM skills. Two reports from outside of Australia formed the basis of the skills list utilised by DAE in sourcing the data: STEM Cognitive Competencies: Knowledge, Skills and Abilities (Carnevale et al., 2011); and Youth and Skills: Putting Education to Work (Aring, 2012). These two reports were also examined. The reason for the examination of these primary two reports, and not just the Australian-based secondary account of Prinsley and Baranyai (2015), was due to the focus of this thesis on the development of STEM skills in Australian high school students. A limited set of skills could be included in a survey to be completed by as many employers as DAE surveyed (2014). It was thus deemed prudent to examine the primary sources so as be sure to identify all relevant skills from these reports that could be developed within a secondary school context. The results and analysis of the DAE (2014) survey were then analysed because it provided the perspective of Australian employers. Finally, as two thirds of the STEM workforce within Australia are in the VET sector, a support document released by the National Centre for Vocational Education Research (NCVER, Siekmann & Korbel, 2016) was also examined. This report, which puts forth its own definition of STEM skills, was examined to ensure that the skills valued by the STEM workforce as a whole was represented.

A brief overview of the scope of each of these reports is given to demonstrate what each report had to offer in terms of developing a list of STEM skills suitable for development within a high school context to prepare students for today and tomorrow's workforce.

STEM Cognitive Competencies: Knowledge, Skills and Abilities (Carnevale et al., 2011). Carnevale et al. (2011), in seeking to identify the key competencies characteristic of STEM workers, utilised the Occupational Informational Network (O*NET) database, which was developed in the US in 1998. O*NET is

> A constantly-updated database of over 960 occupations, O*NET contains information on the key features of an occupation using a standardized, measurable set of variables. Variables include tasks within an occupation, and the knowledge, skills, and abilities, as well as interests and values, as well as other descriptors. O*NET is sponsored by the Department of Labor's Employment and Training Administration [in the US]" (Carnevale et al., 2011, p. 96).

Work interests and values[11] contribute to a person's decision to study and work within the STEM discipline and are important factors in determining the career path people will ultimately follow (i.e. within and/or beyond STEM). However, it is the cognitive competencies (knowledge, skills, and abilities) outlined within O*NET that are of particular interest to this study as the foundations for the competencies that might be developed within the high school context. Carnevale et al. (2011) articulate the STEM knowledge, skills and abilities that they identified through the O*NET database. These were examined and aspects that were suitable for development within a school context were identified.

Terminology clarification. Before moving onto a description of the next report, it is necessary to take a moment to explain the basis of some terminology within Carnevale et al.'s (2011) work and O*NET and to indicate what assumptions will be made regarding terminology when analysing their report for the purposes of this study.

Carnevale et al. (2011) use the term *competencies* when speaking in general terms, particularly regarding the STEM competencies that are seen to be valuable by STEM and non-STEM employers alike. For example, "We find that the diversion of STEM talent – which ultimately results in its overall scarcity – owes to the transferability of some STEM competencies into other academic disciplines" (Carnevale et al., 2011, p. 10).

While the distinction between *knowledge* and *skills* or *knowledge* and *abilities* is self-evident, the same cannot necessarily be said of *skills* versus *abilities*. In terms of how they are utilised within O*NET, *abilities* are defined as

> relatively enduring attributes of an individual's capability for performing a range of different tasks. Abilities are regarded as traits in that they exhibit some degree of stability over relatively long periods of time. It is recognised, however, that abilities may develop over time and with exposure to multiple situations (Fleishman, Costanza, & Marshall-Mies, 1999, p. 175).

Skills on the other hand are "predicated, in part, on the individual's possession of relevant underlying abilities" but are "more dependent on learning and represent the product of training in particular tasks. Skills are more situational and tend to improve" (Fleishman et al., 1999, p. 175). They were included within O*NET in recognition of the fact that employees need to continually develop, refine and indeed acquire new skills in order to remain productive in an ever-changing workforce landscape. Within O*NET there is a hierarchy between *basic skills,* those required for learning content and processes, and *cross-functional* skills, such as problem solving (Anthoney & Armstrong, 2010).

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[11] Defined by O*NET as "preferences for work environments" and "global aspects of work that are important to a person's satisfaction" (Carnevale et al., 2011, p. 97) respectively.

Whilst acknowledging the distinction made between abilities and skills used by Carnevale et al. (2011), the word *skill* alone will be used in this work for simplicity, given that this is the most frequently used descriptor in the literature more broadly and that *skills* are the focus of this study.

Youth and skills: Putting education to work (Aring, 2012). In a background paper prepared for UNESCO's Educational for All Global Monitoring Report in 2012, *Youth and skills: Putting education to work,* Aring (2012) examined 120 employer surveys from developed as well as developing countries to examine skill gaps and how they affect young people in particular. It was concluded that

> The gaps in skills are caused by two converging factors: a qualitative skills mismatch where companies do not find graduates employable even when they have the right qualifications on paper, and a quantitative mismatch where not enough young people are educated and trained at certain levels or they out-migrate to countries where they can earn higher wages (Aring, 2012, p. 5).

While this comment was made regarding employability in general, the issues identified have strong parallels with the STEM workforce paradox as outlined in Chapter 3. The report by Aring (2012) was examined from the perspective of the type of employability skills desired by employers in general. While some of the skills identified are specific to a workplace context rather than a school, an examination of the list presented by Aring (2012) helped to identify a broader range of skills suitable for development within schools than would have been possible if only the work of Prinsley and Baranyai (2015) was consulted.

Australia's STEM workforce: a survey of employers (Prinsley & Baranyai, 2015). In 2015 the OCS commissioned DAE to survey employers on the STEM skills they valued amongst their employees. The lack of clarity within the broader literature regarding the phrase STEM skills was noted within the report. It was acknowledged that the phrase includes not only skills and attributes required solely by STEM disciplines, but also those that would be applicable to employment in a range of other areas (DAE, 2014), hence the inclusion of the work of Aring (2012). Following the examination of the two reports from which the skills in the DAE (2014) survey were taken, the skills in the survey instrument and findings within the OCS report (Prinsley & Baranyai, 2015) were examined. This report was analysed with a particular focus on the skills deemed to be 'important' or 'very important' across a range of employment fields. This enabled a determination of the relative importance of a set range of skills by employers within and beyond STEM. The relative skill level of STEM and non-STEM trained employees across each of the 13 skills used within the DAE (2014) survey was also analysed. Again, skills appropriate for development in high school were the focus.

Defining 'STEM' skills: review and synthesis of the literature (Siekmann & Korbel, 2016). This support document was produced to provide additional information to complement the reports *What is STEM? The need for unpacking its definitions and applications* and *Measuring STEM in vocational education and training* available from NCVER. The support document aims "to clarify the definitions relating to STEM competency and to identify the place of vocational education and training (VET) in delivering the STEM skills required in the twenty-first century" (Siekmann & Korbel, 2016, p. 5). Siekmann and Korbel (2016) put forth their own definition of STEM skills that was embedded within the context of the VET sector. Siekmann and Korbel (2016) thus contribute a unique perspective, as most literature focuses on employment that requires at least one university degree. As high schools prepare students for higher education within the university and VET sectors, a consideration of STEM skills through a VET lens helped to round out the literature base being consulted. When determining STEM skills suitable for development and assessment within schools specifically, it is important to consider the VET sector as it makes up two thirds of the Australian STEM sector (Baranyai et al., 2016).

STEM Skills in Schools. In identifying the skills from each of these reports that would be suitable for development within a high school context, the skills were grouped based on commonalities into five key domains, each with a range of examples of skills that would fit into each domain. Each domain is briefly discussed, its inclusion justified, and a non-exhaustive list of examples of skills for each domain are defined.

Research Question 1b – What are STEM skills according to Australian Year 7-10 STEM teachers?

A key aspect of this study was the gathering of data straight from Australian teachers so that teacher perspectives on STEM skills could be compared with those which emerged from the broad literature base consulted in 1a. This was performed via a survey. The survey contributed to answering Research Questions 1b and 2b. The majority of the survey contributed to addressing Research Question 1b and therefore more detail will be provided here; the components specifically related to addressing Research Question 2b will be presented in that section.

Choice of methods. The research being conducted in this part of the study is descriptive and exploratory in nature (Lodico, Spaulding, & Voegtle, 2006). An online survey with a combination of fixed-response and open-response questions was utilised. Questions that sought quantitative data, predominantly pertaining to demographics, were graphed and, where possible, compared with national samples to see how the sample of teachers who responded compared with the population of Australian teachers. Inductive coding and categorisation were used to analyse the qualitative questions (Saldana, 2016).

Choice of survey method, sampling and delivery. As most of the literature pertaining to STEM education comes from the US, a questionnaire to be distributed nationwide was chosen to get a holistic picture regarding STEM education in Australia. Responses from all states and territories as well as the three schooling sectors (government, Catholic and independent) were sought. An online questionnaire was chosen as it would allow for the most efficient data collection, being simple to distribute and easy for teachers to complete on any device at any time. A link to the questionnaire was available on Facebook (through various STEM related groups and shared publicly) and Twitter and was also distributed via email to many schools.

Development and piloting of the questionnaire. The questionnaire was developed in the first half of 2017 through consultation with supervisors, advisors and teachers. The Australian National University Human Research Ethics Committee (Protocol 2017/277) approved the research on 20th July 2017 and it was piloted by five teachers from a range of STEM learning areas at Burgmann Anglican School and by a lecturer in teacher education from the University of Canberra with the teachers being asked to complete the survey again a week later to establish test-retest reliability (Lodico et al., 2006). After each person completed the survey they were asked for feedback, in particular around whether the title was a clear indicator of the content of the survey, if wording within questions was clear in order to establish validity and whether they had any suggestions of questions that should be added to ensure all relevant issues were included to establish face and content validity (Lodico et al., 2006). The complete questionnaire may be found in Appendix A. At the end of Appendix A there is an explanation of which questions were maintained for analysis within the thesis. The rationale behind the additional questions which may be analysed in subsequent work is also provided.

Data collection. All state and territory Departments of Education and Catholic Education Offices were contacted to ask for permission, if needed, for teachers in their jurisdictions to participate in the survey. In some instances no permission was required, in others it could be granted at that level, and there were some jurisdictions that required the Principal's permission from all participating schools. In the latter case, email contact for all schools' Principals or front office staff were obtained. A letter addressed to the Principal, including a consent form and a link to the questionnaire, was emailed to all relevant schools. In order to increase the sample size, contact details of all independent schools were obtained and a similar letter sent to the Principals. The format of each of these letters to Principals in all cases were essentially the same but tailored to the addressee in each case. An example has been provided in Appendix B.

The survey was open from 24 July 2017 until 15 December 2017. The Australian National University's Centre for Public Awareness of Science (CPAS) SurveyMonkey account was utilised as it is a free service for CPAS students and had all required question format types. At the conclusion of the survey all results were exported to Microsoft Office Excel (2016). Quantitative analyses were done using Excel and open-ended questions were analysed qualitatively. The state/territory and educational sector of all respondents were the first responses to be checked, and anyone found to have participated from a jurisdiction that had not granted permission were immediately excluded.

The questionnaire. The STEM Skills in Australian High Schools questionnaire comprised 39 questions spread across 13 pages (Appendix A). Piloting of the questionnaire and SurveyMonkey indicated that the survey could be completed in 20-30 minutes.

The first 14 questions pertained to the demographics of the participant and their school and respondents were to select the applicable option from a provided list. There was an ‘Other’ response, which respondents could tick and then type an answer if necessary. Some questions required a short-written response. The remaining questions were opinion based. Some involved question formats already described, while others involved Likert scales. Many questions allowed room for an optional comment.

Rationale for the questions. The questionnaire had seven distinct sections. The rationale of each of the four sections which were ultimately analysed for this research will be discussed. Three sections of the questionnaire were not ultimately included within this work. One pertained to the models of STEM being used in Australian high schools. Analysis of this data may be used for an article to demonstrate the variety of ways STEM education is being approached within Australia. The remaining two sections pertained to the development and assessment of the STEM skills obtained from the literature. This data may be used in an article to highlight strategies that have been found to be effective as well as to highlight common challenges teachers face when implementing STEM.

Survey Section 1 – Demographics of the respondents and their school. Several questions were asked at the start so that a picture of the respondents could be determined. This was important in assessing the validity with which results can be extended to describe Australia more broadly. Unfortunately, there is not a body in Australia at this time that houses demographic information pertaining to teachers. However, the Australian Institute for Teaching and School Leadership (AITSL) is in the process of developing the Australian Teacher Workforce Data strategy (ATWD) which will unite data from pre-existing sources to information obtained via the ATWD teacher survey.[12] This will

[12] “The AWTD is a joint initiative between, and is funded by, all state, territory and Commonwealth governments. It is being implemented by AITSL in partnership with the Australian Government Department of Education and Training, the states and territories, teacher regulatory authorities and the Australian Institute of Health and Welfare (AIHW)” (AITSL, 2017).

be helpful for supporting research pertaining to Australian teachers as finding information about their demographics at present is challenging and requires data to be obtained from multiple sources.

Data for comparing demographics between survey respondents and Australia's teaching population were obtained from the final ACER report on the findings from the 2013 Teaching and Learning International Survey (TALIS), an OECD survey conducted for the first time in 2008 and again in 2013 (Freeman, O'Malley, & Eveleigh, 2014). TALIS 2013 sampled over 2000 lower-secondary teachers (Years 7-10) and 149 Principals across 149 schools, which covered all Australian states and territories as well as the three schooling sectors. The survey was conducted between September and December of 2012. There was an 82.6% participation rate from schools and 85.8% teacher participation rate, which was stated to be above the requisite participation rate to meet sampling standards (Freeman et al., 2014). Data was also obtained from the ABS' publication on Schools in Australia, which sources data from the National School Statistics Collection. The ABS issued an overview of "statistics on students, schools, and staff involved in the provision or administration of primary and secondary education, in government and non-government schools, for all Australian states and territories" (ABS, 2018a, para. 1). The 2017 report from the ABS was most appropriate for comparison as teachers completed the survey of this study in that year.

Questions used to determine an overall picture of the participating teaching population pertained to sex, age range, years spent teaching, level of education, geographic information and the area/s of STEM in which they are qualified and those in which they teach.

Survey Section 2 – Awareness of the phrase 'STEM skills'. As the questionnaire was focused upon STEM skills, it was important to establish how familiar teachers were with this concept. Respondents were asked whether they were familiar with the phrase 'STEM skills' and, if so, through what avenues.

Survey Section 3 – What are 'STEM skills' according to Australian teachers? This was the key component of the survey in that it allowed a determination to be made about what Australian teachers consider to be 'STEM skills'.

Teachers were asked to list five-to-ten things that they associated with the phrase STEM skills. The responses to this question were examined individually and those containing more than one distinct idea were split to facilitate classification. To obtain an overview of how teachers responded to this question the responses were entered into WordClouds.com, a word cloud generator. Word clouds display entries with the size of the word being proportional to the number of times it features within the entered data. Settings were adjusted so that only words or phrases that appeared at least three times were included. It is important to note that at this stage, similar entries were not converted to be identical, thus ‘problem solving’ and ‘problem solving skills’ for example are registered as two different things by WordClouds.com. As this was just a preliminary step to get a feel for the types of skills identified by teachers, the data was left untouched apart from splitting multi-idea responses into separate statements.

Having obtained an overall picture, the responses were then examined and grouped into categories. Initial attempts to categorise the responses indicated that many responses could be categorised in multiple ways. Therefore, each response was tagged into as many categories as were applicable in an inductive manner, the categories emerged from the responses themselves (Saldana, 2016). Once the entire data set had been tagged all entries were tagged again, this time deductively, using the categories that emerged the first time, to ensure consistency in how responses were categorised. Each of the final categories that emerged from the data was then considered individually and, categories with broader ranging responses, were sub-categorised to enable emerging themes within categories to also be discussed (Thomas, 2006).

Section 4 of the survey will be outlined within the description of Research Question 2b.

Research Question 1c – How do the perspectives on STEM skills from the literature and Australian Year 7-10 STEM teachers compare?

In order to address Research Question 1c, it was necessary to compare the findings from Research Questions 1a and 1b. Overlaps were noted and skills identified from the literature or the teachers which were not identified by the other are discussed.

Summary

The STEM skills suitable for development and assessment in schools identified from the reports used in 1a are what will be referred to as the ‘literature perspective’ throughout the remainder of the thesis, unless qualified to mean the more conventional literature. Those skills identified by teachers in 1b will be referred to as ‘teacher perspectives’. Part 1c enabled conclusions to be drawn regarding the degree of consensus between the literature and teachers on the nature of STEM skills.

Research Question 2 – To what extent does the Australian Curriculum support the development of STEM skills?

This section of the research focused upon the components of the Year 7-10 Australian Curriculum that may facilitate the development of STEM skills. A brief descriptive overview of the structure of the curriculum is provided first so that readers who are not familiar with the curriculum can gain an understanding of its key facets. Having introduced the key components of the curriculum, an outline of how the curriculum was analysed is provided. Finally, Section 4 of the survey described in Research Question 1b, which pertains to teacher familiarity with various aspects of the Australian Curriculum, is described.

Research Question 2a – STEM skills in the Australian Curriculum

The Australian Curriculum website, *https://www.australiancurriculum.edu.au/*, houses all curriculum-related matter for teachers, parents and other stakeholders. It is a vast website which requires some familiarisation to enable effective and efficient use (for a more complete overview, see Appendix C). The Australian Curriculum is arranged around three dimensions: general capabilities; cross-curriculum priorities; and the learning areas. It is these aspects of the curriculum which will be the focus of this study. In terms of the learning areas, the focus will be upon Science, Mathematics and the Technologies as these represent STEM within the Australian Curriculum.

General capabilities. The general capabilities of the Australian Curriculum are: literacy, numeracy, information and communication technology (ICT) capability, critical and creative thinking, personal and social capability, ethical understanding, and intercultural understanding. It is evident from this that the general capabilities are a focus of the Australian Curriculum as a means of ensuring that students develop, amongst other things, the skills they need to contribute meaningfully to their workplace and society. It is noted that

> Teachers are expected to teach and assess general capabilities to the extent that they are incorporated within learning area content. State and territory authorities will determine if and how student learning of the general capabilities is to be further assessed or reported (ACARA, 2013c, para. 3).

Icons are used throughout the online sequence of content for subjects to indicate to teachers which content descriptions may be appropriate to use to develop a specific capability.

To help teachers in the development of a common understanding of the general capabilities, and to assist them in planning their courses in a manner that enables their students to develop these capabilities, a range of support materials has been provided. Each general capability has an introduction which outlines the underlying rationale for each capability and how it sits within the learning areas. Each general capability is made up of several elements and sub-elements and these underpin the learning continua provided for each capability. These continua are designed to map paths of development of the capabilities that teachers can use to help their students to progress along at their own pace. Finally, each learning area has a document which provides a brief overview of the capabilities (this section is the same for each learning area) and a couple of paragraphs per capability that explain how they may be developed within that learning area specifically.

Cross-curriculum priorities. The other overarching component of the Australian Curriculum are the three cross-curriculum priorities: Aboriginal and Torres Strait Islander Histories and Cultures; Asia and Australia's Engagement with Asia; and Sustainability. These priorities were identified in the Melbourne Declaration as "key areas that need to be addressed for the benefit of individuals and Australia as a whole" (ACARA, 2011, pp., para 1). As with the general capabilities, the cross-curriculum priorities are designed to be addressed across the learning areas within appropriate contexts. There is another set of icons used for the cross-curriculum priorities throughout the website to aid teachers in identifying areas which align with these priorities.

Each priority is described via an overview that indicates key concepts and associated organising ideas that are designed to help support the integration of the priorities within the learning areas. No learning continua are provided for the cross-curriculum priorities. A small amount of learning area specific advice is also provided to help teachers see how they may address the priorities within their learning area (ACARA, 2011).

Learning areas. There are eight compulsory learning areas within the Australian Curriculum: English, Mathematics, Science, Humanities and Social Sciences, The Arts, Health and Physical Education, Languages, and Technologies. Most of these learning areas are comprised only of the subject of the same name with the exception of the Humanities and Social Sciences, which is made up of History, Geography, Economics and Business, Civics and Citizenship for Years 7-10; and the Technologies, which is comprised of Design and Technologies and Digital Technologies.

Each learning area has a separate page for its Rationale, Aims, Key Ideas, Structure, Sequence of Content and Sequence of Achievement. The Rationale for each learning area is normally quite short, three to five paragraphs, and provides an overview of the subject area, the motivations behind it and what makes it a valuable area of study. The Aims for each learning area are articulated via a series of dot-points about what that learning area aims to ensure for the students undertaking it. The Key Ideas are generally small in number and serve as themes that permeate the learning area from Foundation through to Year 10. The Structure page provides information on how the curriculum of each learning area is structured as this varies to an extent from area to area. The Sequence of Content is provided as a PDF in table form which outlines each of the content descriptions within each strand of the curriculum for that learning area from Foundation to Year 10. Finally, the Sequence of Achievement is another PDF tabular document, with two paragraphs for each year level or band of years. In this way, the Sequence of Achievement provides information on the depth to which students should understand and be able to demonstrate the knowledge and skills articulated in the content descriptions (ACARA, 2015s).

The website also presents the sequence of content and achievement in a more dynamic way in which a specific year level can be selected, leading to the provision of a Level Description (overview of how the content of that learning area is structured and the key content covered); Content Descriptions (short descriptions of key content that must be covered – identical to the Sequence of content PDF); Elaborations (examples of how to address content descriptions, these are not available in the PDF version); Achievement Standards (identical to the Sequence of Achievement PDF); and Work Samples. The content descriptions are organised under strands relevant to the learning area. Each descriptor is tagged with icons pertaining to relevant general capabilities and/or cross-curriculum priorities to help teachers to see how these may be addressed within the learning area. This tagging of relevant general capabilities and cross-curriculum priorities for each content description and elaboration is not provided in the PDF downloadable version.

Greater detail on the layout of the ACARA website can be found in Appendix C for those readers who are unfamiliar with its layout and would like to know more or see what it looks like.

Analysis of the Australian Curriculum for STEM skills. Version 8.4 of the Australian Curriculum was released on 26 October 2018. This release included additional elaborations for the Aboriginal and Torres Strait Islander Histories and Cultures cross-curriculum priority for F-10 Science and some updates to the Humanities and Social Sciences curriculum. The latest changes to tagging of all other general capabilities and cross-curriculum priorities was in Version 8.2 (30th June 2016). The most recently endorsed revisions to the F-10 Australian Curriculum for all STEM learning areas has been unchanged since Version 8 (18 October 2015) (ACARA, 2018a).

STEM skills encompass a range of skills that extend beyond those that may be considered unique to the STEM disciplines. Therefore, it was decided that in addition to the STEM learning areas (Mathematics, Science and the Technologies (comprising Design and Technologies and Digital Technologies)), the general capabilities and cross-curriculum priorities ought to be examined as they are fundamental and overarching components of the Australian Curriculum.

Choice of analysis methods. The aforementioned components of the Australian Curriculum were predominantly analysed using a general inductive approach (Thomas, 2006). The relevant sections of the curriculum were printed from the website. They were read through and a highlighter was used to identify any skills (not just those identified as STEM skills from Research Question 1a) throughout. This was repeated twice (for a total of three times) to ensure that no skills had been missed. The skills identified in each component of the curriculum were entered into Excel for sorting. The skills within each component of the curriculum were read closely so that themes could be determined. Identified themes were used to categorise the skills so that the types of skills included within the curriculum could be discussed. This process was utilised to analyse:

- the description of each general capability, its learning continua and the learning area advice for Mathematics, Science and the Technologies;
- the description of each cross-curriculum priority (no learning continua or learning area advice provided by ACARA as was the case for the general capabilities);
- the rationale, aims, key ideas, structure, sequence of content and sequence of achievement for Mathematics, Science and the Technologies. These were analysed individually so that comparisons between the types of skills identified in different sections could be compared.

The other component of curriculum analysis was a quantitative determination of the representation of general capabilities and cross-curriculum priorities in the learning areas. ACARA provides a description of how each general capability might be developed within the learning areas. It is noted that "the learning area or subject with the highest proportion of content descriptions tagged with Literacy[13] is placed first" (ACARA, 2013f, pp., para 30). This information was used to determine the median rank of each learning area in terms of the capacity for development of the general capabilities. This was done to obtain some overall insights into the capacity for development of each general capability within each of the learning areas. This was extended by the researcher tallying the general capability icons on content descriptions and elaborations from Year 7-10 in each of the STEM learning areas.[14] This data was used within the presentation of each general capability and cross-curriculum priority to examine the extent to which each are demonstrated within each of the STEM learning areas. This data was also used in the analysis of the STEM skills developed within each learning area in which a graph showing the proportion of content descriptions and elaborations tagged with each general capability, and another with the cross-curriculum priorities.

Part 2 – Teacher perspectives on the Australian Curriculum

Section 4 of the survey described under Research Question 1b was an optional component of the survey. This was because not all respondents were teaching the Australian Curriculum as it had not been mandated for all learning areas in all states and territories by 2017 (ACARA, 2014c). As a result of only a subset of respondents being able to answer this section of the survey, key demographics were repeated for this section as described in Research Question 1b.

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[13] The same sentence with the general capability replaced is used within each of the examined documents and indicates that the learning areas are discussed in rank order as the order overall differs between learning areas.

[14] Including 10A for Mathematics, an extension level that contains all the content of the Year 10 course as well as some additional material.

Survey Section 4. Familiarity with various aspects of the Australian Curriculum. By way of gauging familiarity of participating teachers with various aspects of the Australian curriculum, teachers who were implementing the curriculum were asked to use a 5-point Likert scale (not at all, small, moderate, large, very large) to indicate their degree of familiarity with different components of the Australian Curriculum. The results were depicted as a series of stacked boxplots for overall comparison before column charts were made to see finer detail regarding familiarity with each component.

Teachers implementing the Australian Curriculum were also asked about the extent to which they feel the curriculum of a chosen STEM learning area they teach supports the development of STEM skills. This was an open response question, which was sorted by learning area prior to analysis.

Summary

A lot can happen between the production of a curriculum and how it is enacted within classrooms around the country. However, now that Australia has a national curriculum, it was possible to examine the curriculum documents to determine the skills emphasised within it. This serves as a useful first step in identifying the skills that Australian teachers are expected to help their students to develop. As the curriculum for each learning area has so many components (as described in the Overview of the Australian Curriculum) which are all presented separately on the website, it was also important to see which parts of the curriculum teachers are relying on, as it is skills listed within those sections of the curriculum that are most likely to be focused on by teachers in their planning. As the curriculum is still relatively new and is expected to be reviewed in 2020 (Department of Education, Skills and Employment, 2019a), it is of benefit to determine how supportive the curriculum is seen to be by the teachers already implementing the STEM learning areas.

Research Question 3 – To what extent do PISA and TIMSS assess STEM skills?

In light of the fact that Australian students' results in PISA and TIMSS are being used as the predominant means of comparing their STEM skill level with that of their global peers (OCS, 2013b; 2014a) an analysis of the skills these tests measure was undertaken.

The assessment frameworks for PISA and TIMSS were read and the skills articulated within each were identified and grouped into themes in an inductive manner. Given the large amount of detail within the frameworks themselves, the general inductive approach was used to condense the information into a summary format driven by a focus on the aims of PISA and TIMSS – what they declare to assess, and how (Thomas, 2006). What follows is a brief overview of the structure of the assessment frameworks obtained and used for analysis for both PISA and TIMSS.

PISA

Documentation for analysis was obtained from the OECD's iLibrary website, *https://www.oecd-ilibrary.org/*, by searching for PISA assessment frameworks. The frameworks from every completed PISA test from 2000 to 2015 inclusive were obtained for analysis. It was noted that the framework documents grew in depth and detail quite significantly over time. PISA has assessed a range of different domains over its history. Each year reading, mathematical or scientific literacy serves as the major domain with the other two, and any additional domains serve as minor domains. The major and minor domains for each year of testing are shown in Table 6.

Table 6 – Major and minor domains in each iteration of PISA (OECD, 2000, 2003a; 2006, 2009, 2012, 2017)

Year	**Major domain**	**Minor domains**
2000	Reading	Mathematics and science
2003	Mathematics	Reading, science and problem solving
2006	Science	Reading and mathematics
2009	Reading	Mathematics and science
2012	Mathematics	Reading, science, problem solving and financial literacy
2015	Science	Reading, mathematics, financial literacy and collaborative problem solving

The mathematics and science frameworks were examined for each year. As problem solving is so central to STEM, it was also examined for 2003, 2012 and 2015, the only years in which the domain was included. The mathematics and science frameworks generally start with an introduction, which includes a justification for the importance of mathematical/scientific literacy, and is followed by the working definition of said literacies for that year's test. Information on the organisation of the domain is then provided. PISA items are generally a combination of a context, content knowledge and various competencies. Only the latter of those were analysed as it is in the description of the competencies that information pertaining to the skills required to complete the items is provided. The way mathematical and scientific literacy was defined over time was investigated, as was the evolution of the competencies to be assessed over the timeframe of 2000-2015.

Problem solving has been assessed less often yet in a wider range of ways than other parts of the test: pen and paper test for 2003; via a computer in 2012; and again via a computer, but with input being provided by computer agents in 2015 to model the collaborative problem solving process. Again, how PISA defined problem solving over time was analysed, as were the problem solving skills and processes focused upon by the framework documents.

TIMSS

Documentation for analysis was obtained from the IEA's TIMSS & PIRLS website, *https://timssandpirls.bc.edu/*. As TIMSS covers mathematics and science, while PIRLS assesses reading literacy, only TIMSS was analysed in this instance. Links are provided from the main website to each iteration of TIMSS. Since 2003 an assessment framework document, like that analysed in the case of PISA, has been made available and was used to determine what was being assessed. In the case of 1995 and 1999 such a document did not exist and so instead the released items for mathematics and science (two separate documents) were examined as these, in addition to having the released items, had an introductory component, which articulated the overarching assessment goals.

A large proportion of the assessment frameworks is dedicated to the content domain being assessed. Each domain is developed in response to changes being implemented in curricula across the world. In the case of mathematics it is divided into number, algebra, geometry, and data and chance; while in science it is biology, chemistry, physics and earth science (Gronmo, Lindquist, Arora, & Mullis, 2013; Jones, Wheeler, & Centurino, 2013). As this domain is focused on content knowledge, it was not examined in detail. The second domain used within TIMSS is known as the cognitive domain and it is here that skills, thinking skills in particular, are noted. Thus, framework documents and the released items documents in the case of 1995 and 1999 were downloaded and their cognitive domains analysed.

Summary

As a key focus of PISA is the assessment of various literacies, it is worth examining the evolution of the definitions of mathematical and scientific literacy over time to understand what the OECD is aiming to assess. A range of other skills are also required to complete PISA so these were identified. While the TIMSS frameworks were read in full, only the relevant portions (i.e. cognitive rather than content focused) were analysed for the inclusion of skills that are specifically being assessed. The skills assessed by each were compared with those obtained from the literature to determine the extent to which PISA and TIMSS assess STEM skills and thus their efficacy as metrics.

Summary of Chapter 4

This study aims to determine how to best develop and assess the STEM skills Australian high school students will need to succeed in the workforce of today and tomorrow. This was achieved via three separate research questions. The first identified STEM skills from the literature as well as from Australian teachers to see how they compare. The results and analysis for this may be found in Chapter 5. In Chapter 6, the degree to which the development of these skills is supported by the Australian Curriculum is discussed. This was supplemented by teacher perspectives on their familiarity with aspects of the curriculum and the degree to which they felt it to be supportive. Finally, an examination of PISA and TIMSS assessment frameworks was performed and discussed in Chapter

7. This was done by way of determining the skills analysed by these tests by way of determining their suitability as metrics of Australian students' STEM skills. Please note that in each of these three chapters, results and discussion have been intertwined throughout. Links between findings from different research questions will be discussed in Chapter 8.

Chapter 5 – Results and Discussion for Research Question 1 – What are STEM skills?

1a. What are STEM skills according to the literature?

1b. What are STEM skills according the Australian Year 7-10 STEM teachers?

1c. How do the perspectives on STEM skills from the literature and Australian Year 7-10 STEM teachers compare?

Introduction

The first part of the chapter is focused on the construction of a list of STEM skills that are suitable for development within a high school context to address Research Question 1a. No such list was able to be found within the conventional literature; what was present were some governmental and industry reports regarding skills desired by STEM employers. As a key goal of education is to prepare students for life outside of school, skills desired by employers, which could be developed within a high school context, have been used as a proxy for STEM skills within high school education. Reports by Carnevale et al. (2011), Aring (2012), Prinsley and Baranyai (2015), and Siekmann and Korbel (2016) are analysed individually within this chapter, with a focus on the skills outlined by each report that would be suitable for development within a high school context. After an examination of each report, five domains of STEM skills are identified and a non-exhaustive list of examples of skills within each are provided.

In the second part of this chapter, the focus turns to what Australian Year 7-10 STEM teachers consider to be STEM skills in order to address Research Question 1b. The data for this was obtained via a survey conducted during 2017. The demographics of the respondents are presented before moving into an analysis of the survey responses, with a strong focus on their perspectives on STEM skills.

The chapter closes with a comparison of the STEM skills taken from the literature with those identified by Australian Year 7-10 STEM teachers to address Research Question 1c.

Please note that results and discussion are presented together throughout this chapter.

Research Question 1a – What are STEM skills according to the literature?

Reports by Carnevale et al. (2011) and Aring (2012), which served as the predominant primary sources for a survey of Australian employers conducted by DAE (2014) and discussed by Prinsley and Baranyai (2015), along with the work of Siekmann and Korbel (2016) are considered in turn.[15] Following an analysis of the skills identified from each report that would be appropriate for development in high schools, a framework of those skills is presented.

STEM Cognitive Competencies: Knowledge, Skills and Abilities (Carnevale et al., 2011)

This report was examined to get a holistic view of the knowledge, skills and abilities that are desired by STEM employers. Whilst based upon US data, the nature of STEM occupations are not highly variable between the US and Australia and thus this was not deemed to be a significant limitation. Carnevale et al. (2011) presented a range of STEM knowledge, skills and abilities that they identified from an examination of the O*NET database which houses key information regarding almost 1000 different occupations. Carnevale et al. (2011) discussed and outlined a range of knowledge, skills and abilities desired by STEM employers.

STEM Knowledge. The first of the cognitive competencies to be explored is that of knowledge. Many of the set of knowledge competencies are very familiar to educators as they form the basis of the content of courses within the STEM disciplines at the high school level. However, as O*NET is targeting the occupational level, knowledge domains typically not explored at school are also included. The Core Knowledge Domains which were identified by Carnevale et al. (2011) as being most strongly correlated with STEM occupations are described in Table 7.

[15] These reports were chosen despite them not going through a peer review process because they articulate skills more explicitly than conventional literature sources. Having said this, conventional literature sources found to support the findings of the reports have been cited where possible.

Table 7 – Core Knowledge Domains Associated with STEM Occupations (Carnevale et al., 2011, p. 54)

STEM Knowledge Domain	
Production and Processing	Knowledge of raw materials, production processes, quality control, costs and other techniques for maximising the effective manufacture and distribution of goods.
Computers and Electronics	Knowledge of circuit boards, processors, chips, electronic equipment, and computer hardware and software, including applications and programming.
Engineering and Technology	Knowledge of the practical application of engineering science and technology. This includes applying principles, techniques, procedures, and equipment to the design and production of various goods and services.
Design	Knowledge of design techniques, tools, and principles involved in production of precision.
Building and Construction	Knowledge of materials, methods, and the tools involved in the construction or repair of houses, buildings, or other structures such as highways and roads.
Mechanical	Knowledge of machines and tools, including their designs, uses, repair and maintenance.
Mathematics	Knowledge of arithmetic, algebra, geometry, calculus, statistics, and their applications.
Physics	Knowledge and prediction of physical principles, laws, their interrelationships, and applications to understanding fluid, material, and atmospheric dynamics, and mechanical, electrical, atomic, and subatomic structures and processes.
Chemistry	Knowledge of the chemical composition, structure, and properties of substances, and of the chemical processes and transformations that they undergo. This includes uses of chemicals and their interactions, danger signs, production techniques, and disposal methods.
Biology	Knowledge of plant and animal organisms and their tissues, cells, functions, interdependencies, and interactions with each other and the environment.

While the last four entries of Table 7 have clear associations with high school subjects, the earlier listings are much more occupationally aligned, as is to be expected given the origins and purpose of the O*NET tool. Having said this, it is possible that computers and electronics, engineering and technology and design would start to be explored within the technology and engineering aligned STEM subjects at school, such as the Technologies within the Australian Curriculum. Furthermore, the remaining knowledge areas (production and processing, building and construction, and mechanical) may be touched upon via the Design and Technologies curriculum specifically, integrated

STEM projects, work experience placements or Australian School-based Apprenticeships (ASbAs[16]). The last of these seems particularly likely. Given just over two-thirds of the Australian STEM workforce have vocational rather than university qualifications (Baranyai et al., 2016), a larger focus and value ought to be placed on ASbAs within Australian high schools. Many shortages within STEM lie in the vocational fields (Marginson et al., 2013) that students can enter whilst still at school through the ASbA program. This would allow them to develop knowledge in pertinent vocational areas whilst still at school.

STEM Skills. A wide range of skills that are fundamental to STEM occupations were identified within the report by Carnevale et al. (2011) and are summarised within Table 8. These authors found that, while STEM knowledge was somewhat transferable, mathematical knowledge in particular, STEM *knowledge* was much more desirable within STEM occupations than beyond. This is to be expected. STEM *skills* on the other hand were found to be quite common in occupations that lie outside of STEM and were found to be more transferable than knowledge. This helps to explain some of the diversion of STEM-trained workers into non-STEM fields, as they possess skills that are also valued by other occupations. Critical thinking is perhaps the best example of this, with 96% of STEM occupations and 92% of STEM competitor occupations identifying critical thinking as being ‘important’ or ‘extremely important’ (Carnevale et al., 2011).

[16] “An Australian School-based Apprenticeship is an Australian Apprenticeship which is undertaken part-time while the Australian Apprentice is at school. An Australian School-based Apprenticeship arrangement combines paid employment as an apprentice or a trainee, off-the-job vocational training and senior secondary school studies.
An Australian School-based Apprenticeship provides senior secondary school students with hands-on industry experience, and the ability to work towards or complete a nationally recognised qualification, while they complete their senior school certificate” (Australian Government Australian Australian Government Australian Apprenticeships, 2015).

Table 8 – Core Skills Associated with STEM Occupations (Carnevale et al., 2011, p. 55)

STEM Skills Domain	
Mathematics	Using mathematics to solve problems.
Science	Using scientific rules and methods to solve problems.
Critical Thinking	Using logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions, or approaches to problems.
Active Learning	Understanding the implications of new information for both current and future problem-solving and decision making.
Complex Problem Solving	Identifying complex problems and reviewing related information to develop and evaluate options and implement solutions.
Operations Analysis	Analysing needs and product requirements to create a design.
Technology Design	Generating or adapting equipment and technology to serve user needs.
Equipment Selection	Determining the kind of tools and equipment needed to do a job.
Programming	Writing computer programs for various purposes.
Quality Control Analysis	Conducting tests and inspections of products, services, or processes to evaluate quality or performance.
Operations Monitoring	Watching gauges, dials, or other indicators to make sure a machine is working properly.
Operation and Control	Controlling operations of equipment or systems.
Equipment Maintenance	Performing routine maintenance on equipment and determining when and what kind of maintenance is needed.
Troubleshooting	Determining causes of operating errors and deciding what to do about it.
Repairing	Repairing machines or systems using the needed tools.
Systems Analysis	Determining how a system should work and how changes in conditions, operations, and the environment will affect outcomes.
Systems Evaluation	Identifying measures or indicators of system performance and the actions needed to improve or correct performance, relative to the goals of the system.

Mathematics, science and programming are clearly aligned with STEM subjects. Critical thinking, active learning and complex problem solving may be developed across a range of curriculum areas. The place of the other skills in Table 8 within schools is less obvious as they are arguably much more occupation-specific, with many of them having clearer alignment with the technician-side of STEM. However, as was the case with the knowledge domain, it is possible that an early start on the development of some of these skills within the Technologies learning area as well as VET placements or ASbAs, may be possible at the high school level.

STEM Abilities. In a similar fashion to skills, abilities typically require knowledge to solve complex problems, though abilities are considered to be more enduring than skills (Carnevale et al., 2011). Mathematical and deductive reasoning were found to be the most often used abilities within STEM occupations. However, they were also required to a similar extent across the economy. This further emphasises the utility of STEM skills within and beyond traditional STEM fields. The abilities associated identified by Carnevale et al. (2011) from the O*NET data are summarised in Table 9.

Table 9 – Abilities Associated with STEM Occupations (Carnevale et al., 2011, p. 57)

STEM Abilities	
Problem Sensitivity	The ability to tell when something is wrong or is likely to go wrong. It does not involve solving the problem, only recognising that there is a problem.
Deductive Reasoning	The ability to apply general rules to specific problems.
Inductive Reasoning	The ability to combine pieces of information to form general rules or conclusions (includes finding a relationship among seemingly unrelated events).
Mathematical Reasoning	The ability to choose the right mathematical methods or formulas to solve a problem.
Number Facility	The ability to add, subtract, multiply, or divide quickly and correctly.
Perceptual Speed	The ability to quickly and accurately compare similarities and differences among sets of letters, numbers, objects, pictures or patterns. The things to be compared may be presented at the same time or one after the other. This ability also includes comparing a presented object with a remembered object.
Control Precision	The ability to quickly and repeatedly adjust the controls of a machine or a vehicle to exact positions.

Mathematical reasoning and number facility have clear links with the Mathematics curriculum, while problem sensitivity along with deductive and inductive reasoning may be developed across a range of school subjects. Perceptual speed and control precision arguably have far less of a place within high schools, though might be used periodically.

Overall. A selection of knowledge, skills and abilities components outlined by Carnevale et al. (2011) can be extrapolated back to a high school context so that students can develop their competencies in these areas. Those that are appropriate will be grouped with those identified in the reports which follow, in the construction of a framework of STEM skills appropriate for development in high schools.

Youth and skills: Putting education to work (Aring, 2012)

The report by Aring (2012) examines employability skills in general, not within STEM specifically. However, given the difficulty experienced by STEM graduates on gaining employment upon graduation (Marginson et al., 2013; Norton, 2016), it is possible that they are lacking some of the general skills all employers seek in their employees. A difficulty highlighted within the report is how to identify exactly which skills are lacking among youth. Two of the key issues raised were: the lack of a standard skill classification system across both education and industry; and that educational achievement is often used as a proxy for skills (Aring, 2012). It will be worth remembering the latter when examining the use of PISA and TIMSS for assessing STEM skills in Chapter 7.

Employers across the board indicated that schools were not cultivating the desired employability skills within youth (Aring, 2012). This is perhaps at least in part due to the lack of clear articulation regarding the exact nature of the desired skills, something this study seeks to address. As Aring (2012) notes, the generality of a term such as ‘employability’ does not provide curriculum developers and educators with information pertaining to the specific skills that employers feel are lacking. Arguably ‘STEM’ is unfortunately just as vague (Bybee, 2016; Siekmann & Korbel, 2016) and thus the skills framework put forth at the end of Part 1 of this chapter aims to be specific yet not exhaustive in nature.

Aring (2012) used a typology of employability skills that arose from the Educational Development Center’s study on how to improve the transition from school to work. It is shown in Table 10.

Table 10 – Typology of Employability Skills (adapted from Aring, 2012, p. 9)

Skills	**Description**	**Finding**
Cultural	Understanding how work gets done, decoding unwritten rules and navigating the unique culture of a workplace. Knowing how to navigate the workplace culture. Knowing how to be effective with people from other cultures.	Employers considered these skills to be "the most difficult to teach".
Interpersonal	Knowing how to listen, speak and present information.	Employers rated these skills next in order of difficulty to teach.
Intra-personal	Knowing how to manage one's emotions, be comfortable with uncertainty and manage resources.	Employers believed that these skills come from acculturation in families and that these are extremely difficult to teach.
Technical or job specific	How to operate specific tools, processes, machines, software etc.	Employers considered these the easiest to teach but some concern was expressed about employees' ability level, or lack thereof, in the recruitment phase.

While 'knowing how to be effective with people from other cultures' may have a chance of being developed within schools, depending on the socio-cultural breakdown of the school, the other components of the description are not able to be developed within schools. However, they might be cultivated to at least a basic level if students are given opportunities to work within workplaces whilst at school. This may be via part-time jobs, work experience placements or the ASbA program. Interpersonal skills are frequently called upon within a school context within class activities, group work, presentations and so on. Intrapersonal skills, whilst shaped predominantly by the student's family, as indicated in Table 10, have the potential to be developed within a school context. However, the extent to which this may be the case will depend largely on the school. Schools that embed group work throughout their curriculum will provide students with regular opportunities to face uncertainty and to have to manage resources such as materials and time. Furthermore, with the ever-increasing focus on wellbeing within schools, managing one's emotions is entering into the purview of education to a growing extent (Australian Catholic University and Erebus International, 2008; Waters, 2016). Finally, technical or job specific skills, whilst relatively easy to learn on the job (Aring, 2012), may be developed within schools. For instance, students in science may be taught how to use microscopes, electrophoresis kits, and distillation apparatus. Within mathematics they may be taught how to use various graphing software. Within technologies students may learn how to use software used in design as well as how to operate various pieces of machinery. Thus, with the possible exception of the cultural typology, many of the broad categories of skills identified by Aring (2012) are appropriate for development within a high school context.

The typology outlined in Table 10 was used by Aring (2012) in the review of 120 surveys to map the types of employability skills gaps in the global workforce, the results of which are summarised in Table 11.

Table 11 – Employability Skills Gap According to Employer Surveys.

A ✓ indicates that a skill falls into that typology, while ✓✓ indicates that the skill is very strongly developed in that typology (Aring, 2012, pp. 10-11), shaded rows indicate skills *unlikely* to be developed within a school context as determined by the author.

‘Employability’ Skills	Cultural	Interpersonal	Intrapersonal	Technical, job specific
Literacy				✓
Numeracy				✓
Written communications	✓	✓	✓	✓
Ability to use information	✓	✓	✓	✓
Oral presentation skills	✓	✓✓	✓	
Ability to handle large amounts of information		✓	✓✓	
Technical ability				✓✓
Ability to use new information	✓		✓	
Computer literacy				✓✓
Proficiency in English		✓		✓✓
Prior exposure to the work	✓	✓	✓	✓
Knowing the organisation	✓✓	✓	✓	
Understanding economic and business realities			✓	✓
Ability to formulate and check assumptions	✓		✓	
Ability to follow and construct logical arguments			✓	✓
Ability to choose appropriate information to address problems	✓			✓

‘Employability’ Skills	Cultural	Interpersonal	Intrapersonal	Technical, job specific
Ability to plan and execute tasks independently			✓✓	✓
Ability to approach problem solving	✓	✓	✓	✓
Ability to monitor and evaluate own work-related activities			✓✓	✓
Ability to relate specific issues to wider contexts	✓		✓	✓
Ability to apply knowledge to new situations			✓	✓
Ability to devise ways to improve own actions			✓✓	✓
Ability to deal with different cultural practices	✓✓			
Openness and flexibility			✓✓	
Negotiation and mediation skills	✓	✓✓	✓	✓
Self-motivation and initiative			✓✓	
Ability to network	✓	✓✓		
Creativity and innovation			✓✓	
Ability to relate to a wide range of people	✓✓	✓		
Team participation	✓	✓✓		
Sense of Identity and self confidence			✓✓	

The skills listed in Table 11 are on the whole best described as ‘applied skills’ as they must be learned by doing within a relevant context. As such, some are not well cultivated by educational systems, particularly those systems that focus on didactic teaching methods. It should be noted that while the table is said to be a list of employability *skills*, many of the entries begin with *ability*. This indicates that Aring (2012) did not separate the two, lending support to the author’s decision to group the O*NET *skills* and *abilities* under the title of *skills*.

Table 11 shows that most of the employability skills identified by Aring (2012) have been mapped to more than one employability typology (as defined in Table 10), indicating that they are multi-faceted. Rows that have been shaded indicate skills that are less likely to be developed within a school context, all remaining skills might feasibly be developed. Some, such as literacy, numeracy, written communication, ability to use information, oral presentation skills, and computer literacy and so on are fundamental to one or more school subjects. These skills should therefore be well developed within a person's high school education. Others, such as the ability to: handle large amounts of information; formulate and check assumptions; devise ways to improve own actions, and relate specific issues to wider contexts may be developed, but are more subject to the nature of the education system in question. If students are given opportunities to engage in authentic ongoing projects, they are more likely to encounter opportunities to develop these skills. If a didactic teaching approach predominates, where students learn material and then regurgitate that information in a test, many of these skills will not be developed.

Taken together, the typology of employability skills and their mapping to a broad range of 'employability skills' as presented in Table 11 provides useful additional information in developing an understanding of the STEM skills schools may look to develop more strongly in their students. While they are not all necessarily STEM specific, they do all fit into a STEM frame of mind. Furthermore, as they are skills recognised by a wide range of industries, their development within all students would help to make students better prepared for the workforce and more employable across both STEM and non-STEM sectors.

Australia's STEM workforce: a survey of employers (Prinsley & Baranyai, 2015)

This report discusses the results of a survey of Australian employers across a wide range of industries which was conducted by DAE in 2014. Table 12 lists the 13 skills and attributes DAE (2014) used in their survey. The work of Carnevale et al. (2011) was identified as a main source of the skills DAE (2014) chose to include and it was noted that these skills were drawn from each the four typologies outlined by Aring (2012) presented in Table 10. Two columns have been added to Table 12 to demonstrate whether each of the skills used in the DAE (2014) survey were identified by Carnevale et al. (2011) or Aring (2012).

Table 12 – List of skills used in the DAE (2014) survey and whether they were present in the work of Carnevale et al. (2011) or Aring (2012)

Skill/attribute in DAE survey	**Identified by**	
	Carnevale et al. (2011)	**Aring (2012)**
Active learning (i.e. learning on the job)	✓	
Complex problem-solving	✓	
Creative problem-solving		
Critical thinking	✓	
Design thinking		
Interpersonal skills		✓
Knowledge of legislation, regulation and codes		✓
Lifelong learning		
Occupation-specific STEM skills	✓	
Programming	✓	
Systems analysis and evaluation	✓	
Time management		
Understanding how we do business		✓

Creative problem-solving, design thinking, lifelong learning, and time management were not explicitly stated in the work of Carnevale et al. (2011) or Aring (2012) but have been included by DAE (2014). It is unclear exactly where these have come from as their origin is not stated in the report by DAE (2014) or Prinsley and Baranyai (2015). However, it is reasonable to assume that they arose as part of the broader literature review and/or consultation process[17] conducted prior to undertaking the survey.

The value in examining the reports of Carnevale et al. (2011) and Aring (2012) firsthand is that it enabled the identification of some additional skills beyond those listed in Table 12 that are suitable for development in schools. For example, 'occupation-specific STEM skills' as listed in Table 12 is quite vague as it is a collective term for a wide range of skills. The skills associated with STEM occupations, as presented in Table 8 from the work of Carnevale et al. (2011), enabled identification of what type of occupation-specific skills were meant and thus which could be developed at school within Year 7-10. Furthermore, abilities from Table 9, such as various forms of reasoning skills, were

[17] "Consultations in the form of both semi-structured interviews and focus groups were conducted to gain insight into the role and demand for STEM skills, in the Australian work environment.
These sessions were held across Melbourne, Sydney and Canberra during 2013, with approximately 50 participants across a range of industries including the private and public sector. A mix of small, medium and large businesses were also represented" (DAE, 2014, p. 9).

omitted from the list used by DAE (2014). Yet reasoning skills are developed across many school subjects, indeed, reasoning is a component of the critical and creative thinking general capability of the Australian Curriculum (ACARA, 2012a). Likewise, some skills particularly appropriate for development within schools, were identified by Aring (2012) in Table 11. For example, literacy and numeracy are not included in the DAE (2014) survey but are another two general capabilities (ACARA, 2012a) and low levels of both across the workforce are frequently bemoaned by employers (Australian Industry Group, 2016). Finally, a range of specific interpersonal skills are provided by Aring (2012) as well as an assortment of intrapersonal skills that are not all included within the list used in the survey by DAE (2014). These remain vital for employment and thus ought to be developed during schooling.

Returning now to the DAE (2014) survey and some of its key findings. Respondents (employers) were asked about the relative importance of each of 13 skills in Table 12. The skills rated as ‘important’ or ‘very important’ by each industry sector are shown in Table 13.

Table 13 – To what extent are the following skills and attributes important or very important to your workplace? (Prinsley & Baranyai, 2015, p. 3)

Percentage of employers in each industry sector by skill level that answered ‘important’ or ‘very important’. Cells below the 50th percentile of values in the table are coloured red and those above blue.

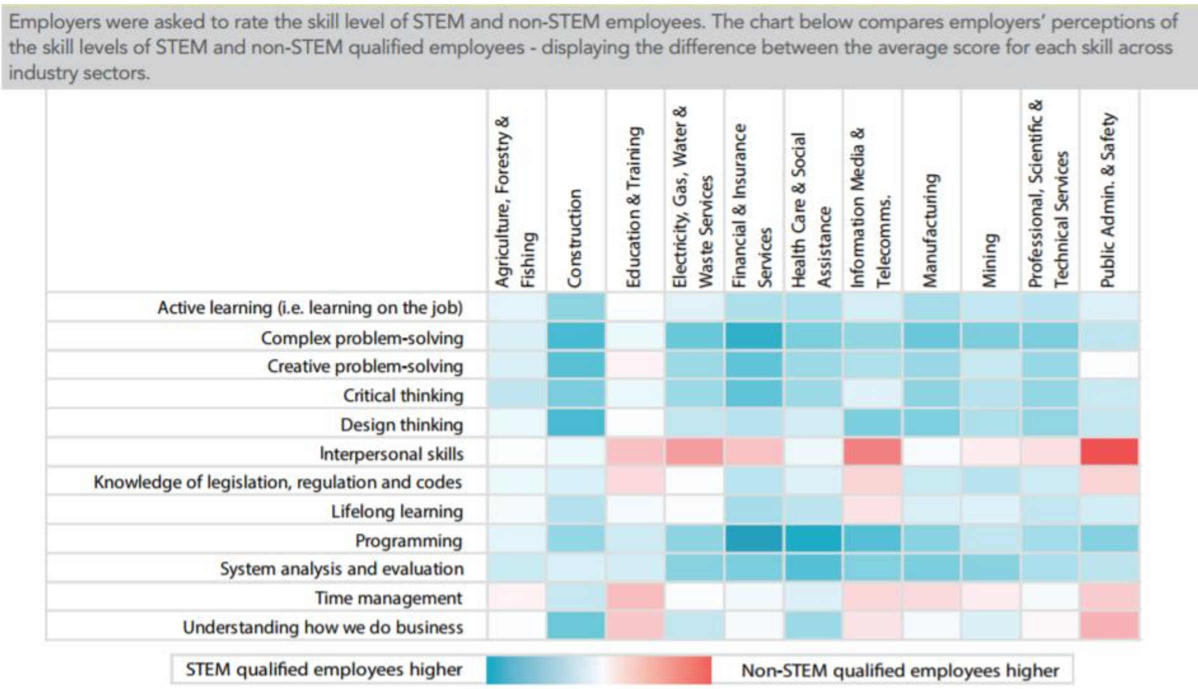
	Agriculture, Forestry & Fishing	Construction	Education & Training	Electricity, Gas, Water & Waste Services	Financial & Insurance Services	Health Care & Social Assistance	Information Media & Telecomms.	Manufacturing	Mining	Professional, Scientific & Technical Services	Public Admin. & Safety
Active learning (i.e. learning on the job)	96	100	83	100	98	82	96	93	94	97	94
Complex problem-solving	75	67	78	86	95	82	91	85	97	97	88
Creative problem-solving	88	89	89	100	83	64	91	87	88	97	76
Critical thinking	75	56	94	100	95	91	91	86	97	92	94
Design thinking	42	75	78	57	47	40	100	83	78	73	47
Interpersonal skills	79	78	94	86	75	91	91	75	71	87	88
Knowledge of legislation, regulation and codes	67	44	61	43	80	82	50	58	59	67	65
Lifelong learning	78	33	94	71	70	64	70	57	70	76	59
Occupation-specific STEM skills	77	56	59	100	78	45	78	71	71	79	76
Programming	14	25	44	57	48	30	86	44	44	41	25
System analysis and evaluation	32	29	56	71	44	60	83	55	47	52	44
Time management	75	78	76	71	70	55	87	78	67	86	71
Understanding how we do business	88	89	94	86	75	100	74	84	85	84	82

Active learning was rated ‘important’ or ‘very important’ by over 93% of employers across almost all industries, indicating that the ability to learn on the job throughout your career is highly valued by most employers. The lowest ratings were given by the Education and Training (83%) and Health Care & Social Assistance (82%) sectors, which is intriguing given that teachers (Riddle, 2015) and health care workers (Iliopoulos, Morrissey, Baryeh, & Polyzios, 2018) do a lot of ‘learning on the job.’

Programming and System analysis and evaluation were not valued strongly outside of Information Media & Telecommunications. Other more discipline-specific skills such as occupation-specific STEM skills and design thinking were generally deemed much less important, yet they were considered to be very important by 100% of respondents from one industry group each (Electricity, Gas, Water & Waste Services and Information Media & Telecommunications respectively). Clearly these particular skills are central to these industries but are not broadly applicable across sectors.

The survey also asked about STEM trained as well as non-STEM trained employees and their relative skill level across the 13 skill areas. Note that the key difference between Table 13 and Table 14 is that the former places the focus on the importance of particular *skills* while the latter asks about whether STEM or non-STEM trained *employees* are typically more proficient in each skill.

Table 14 – Comparison of STEM qualified and non-STEM qualified employees (Prinsley & Baranyai, 2015, p. 4)



It can be observed from Table 14 that STEM qualified employees were rated more highly across each of the skills and sectors with only a couple of exceptions. Most evidently, non-STEM qualified employees rated substantially more positively in interpersonal skills, indeed this was an area of concern for employers regarding their STEM graduates. These skills are in many ways linked with communication, which was identified by respondents as the most important skill which was missing from the list in the survey (DAE, 2014). Whether it be collaboration within a team or engagement with clients and the media, communication within the modern working environment is key. Employees across the board, from roles in the communications office through to those in technical positions, need to be able to communicate with people within and/or beyond the organisation (DAE, 2014).

Interestingly, while Table 14 indicates that 'interpersonal skills' was an area in which non-STEM qualified employees were generally claimed to be more proficient, only 46.4% rated 'interpersonal skills' as 'very important' (DAE, 2014). Employers were asked within the survey whether they agreed with the statement "STEM qualified people do not have good interpersonal skills" (DAE, 2014), with the results being depicted in Figure 6.

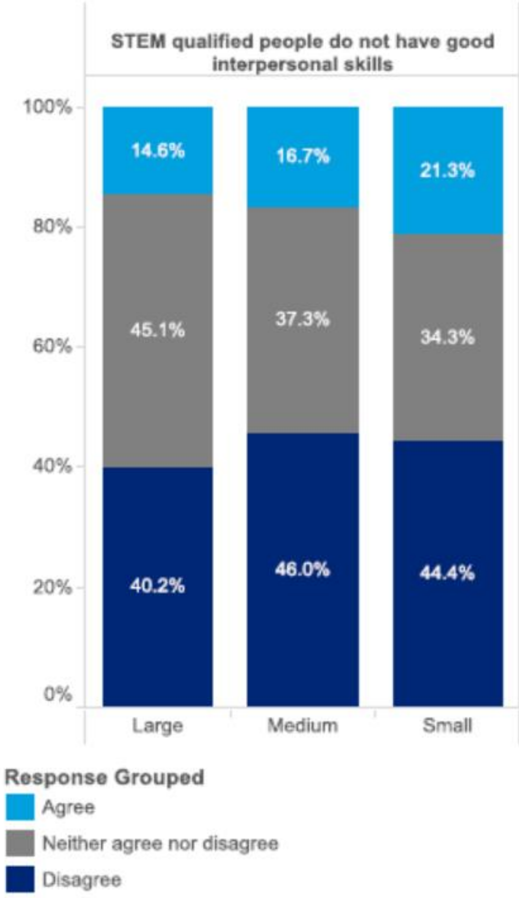


Figure 6 – Response to statement 'STEM qualified people do not have good interpersonal skills', by business size (%) (DAE, 2014, p. 27)

While 21.3% of small business employers agreed with this statement, on average across all business sizes, only 17.6% agreed. Furthermore, respondents indicated that a lack of interpersonal skills was more apparent during recruitment than among employees already within the workplace (DAE, 2014). This indicates that while STEM graduates may not present as well during interviews, once within the workplace there is no substantial deficit in their skills in this area. The sense of poor interpersonal skills during recruitment may, however, be a contributing factor to STEM graduates experiencing difficulty in obtaining employment (Norton, 2016).

Returning to Table 14, time management demonstrated no strong pull towards employees of STEM or non-STEM qualification, with low-level responses for both across all industries. This trend was also observed for understanding how we do business. The Construction and Health Care & Social

Assistance industries were the only ones to rate STEM qualified employers more highly across every skill, closely followed by Agriculture, Forestry & Fishing for which time management was weakly in favour of non-STEM qualified employees. However, it is important to note that this particular industry had the weakest responses in either direction, indicating STEM and non-STEM qualified employees were deemed almost equally competent across the skills. Education & Training and Information, Media & Telecommunications were the industries that demonstrated the strongest preference for non-STEM qualified employees, though even these industries only rated non-STEM qualified employees more highly on five of the 13 skills.

STEM-qualified employees were rated more highly by all industries for active learning, complex problem-solving, critical thinking, design thinking, programming, and system analysis and evaluation, which is just over half of all the skills investigated. Furthermore, non-STEM employees were only rated more highly by Education & Training for creative problem-solving and Information Media & Telecommunications for lifelong learning. This leaves only knowledge of legislation, regulation and codes, and understanding how we do business, in addition to the previously mentioned interpersonal skills and time-management, as skills for which non-STEM qualified employees were rated more highly in three to seven of the industries studied. The high rankings for STEM-qualified as opposed to non-STEM qualified employees across the majority of skills and industries reinforces why it is easy for STEM qualified workers to move in and out of STEM fields in the manner described by Carnevale et al. (2011).

The work of Prinsley and Baranyai (2015) is of importance for this study as it analyses a survey of Australian employers; the reports of Carnevale et al. (2011) and Aring (2012) are from overseas. The relative importance of the skills used in the survey by DAE (2014) are useful in identifying skills of importance to STEM employers. Taken together with the background work of Carnevale et al. (2011) and Aring (2012) a broader picture of the skills Australian students would benefit from learning at school is able to be painted. However, one additional report was chosen for analysis as it was presented from the perspective of the Australian VET sector as it comprises two thirds of the Australian STEM workforce (Baranyai et al., 2016).

Defining 'STEM' skills: review and synthesis of the literature (Siekmann & Korbel, 2016)

Siekmann and Korbel (2016) also drew on the work of Carnevale et al. (2011) and Prinsley and Baranyai (2015) but not directly from Aring (2012). The third key source used by Siekmann and Korbel (2016) was a World Bank Policy Research Working Paper by Cunningham and Villasenor (2016), which examined skills employers want. Cunningham and Villasenor (2016) propose that labour-market skills can be divided into cognitive skills (basic cognitive, higher-order cognitive and technical) and socio-emotional skills. Siekmann and Korbel (2016) decided to "define STEM skills primarily as technical skills and distinct from higher-order thinking skills and social-emotional skills" (p. 44) and argue that the term 'STEM skills' should in fact not be used at all, as it is so poorly defined. They suggest that narrower terms such as 'technical skills' or 'cognitive skills' be used instead to provide clarity about what skills are meant. The decision by Siekmann and Korbel (2016) to focus on technical skills is understandable in that they are the most STEM-specific and their report was written with a focus on the VET sector. However, given high school education seeks to prepare students for future employment in any area, the decision has been made in this work to maintain the broader skill areas identified in each of the preceding reports when proposing STEM skills suitable for development in high schools. As the work of Siekmann and Korbel (2016) drew their list of technical STEM skills out of the work of Carnevale et al. (2011) and Prinsley and Baranyai (2015), no further analysis is required here.

Taking skills from the workplace into schools

The preceding reports were all focused upon the STEM skills, and competencies more generally, which are desired by STEM employers. It is generally accepted that schools are the starting point of the STEM pipeline and that if we want a strong STEM workforce and STEM literate society, the focus on STEM skills needs to start within schools (OCS, 2014a). Indeed, in a report by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) on Youth and Skills it was stated that,

> secondary school is an important channel through which young people acquire skills that improve opportunities for good jobs … skills learned at school need to extend beyond subject knowledge. Employers repeatedly indicate that they value transferable skills such as applying knowledge in real work situations, solving unexpected problems and communicating effectively with colleagues (UNESCO, 2012, p. 246).

Schools are intrinsically different from a workplace, though they do have some similar characteristics and, as indicated by the UNESCO (2012), are an important starting point for the development of the skills that are required for success in the workplace. The four reports discussed within this section outlined skills for the *workplace*. In the following section they will be used to propose a list of STEM skills that are appropriate for development within *high school*. This will serve as the 'literature perspective' on STEM skills for the remainder of this study.

A Framework for STEM skills in schools. By way of creating a framework for STEM Skills in Schools, the skills identified in the previous sections were examined with careful attention being paid to the identification of skills most suited to development within schools. These were categorised into five key domains and defined by way of providing a framework to use within this study.

The skills identified from the previous section as being the most suitable for development in schools were grouped into five overarching domains:

- literacy skills, comprised of each of the disciplinary literacies as well as STEM literacy as defined in Chapter 2;
- disciplinary skills, those disciplinary specific or technical skills most suited to development within schools;
- higher order thinking skills, which are not necessarily confined to STEM disciplines yet are vital for high performance and greatly valued by employers;
- interpersonal skills, those which involve interactions with other people; and
- intrapersonal skills, those skills that are largely about the self and managing one's emotions.

Skills that came from Carnevale et al.'s (2011) study based on O*NET competencies were defined within that report and so their definitions were used here. The remaining skill areas were not defined in any of the reports analysed and hence additional research was undertaken to provide a definition for each skill. References to specific skills within the conventional peer-reviewed literature were also examined by way of providing additional support to the choice of skills. Each skill domain, and the examples of skill each comprise, will now be presented along with arguments for their inclusion.

Literacy. While only Aring (2012) included literacy in their list of skills, a key goal of STEM education is to increase students' STEM literacy, as discussed in Chapter 2. Furthermore, the Survey Report: Workforce Development Needs released by the Australian Industry Group (2018) indicated that employers found literacy skills to be underdeveloped in many workers, suggesting that it needs greater attention at school. Information/digital literacy has also been identified in the conventional literature as being particularly important within STEM (Cheng, 2019; Eppes, Milanovic, & Sweitzer, 2012). Literacy is a general capability within the Australian Curriculum (ACARA, 2013f) that places a focus not just on general literacy but also on disciplinary literacies. Thus, literacy skills are very appropriate for development within high school. As STEM literacy is taken to be more than the sum of its component parts, the literacy domain is comprised of the four disciplinary literacies as well as STEM literacy.

Literacy, numeracy and computer literacy feature within the employability skills detailed by Aring (2012) (Table 11), though these have been already been incorporated across the four disciplinary literacies (scientific, technological, engineering and mathematical) as outlined in Chapter 2. Numeracy has some overlaps with mathematical literacy, and computer literacy fits within technological literacy. Literacy and numeracy were coded as 'technical, job specific' skills by Aring (2012), however, in light of the broader definitions included here for each disciplinary literacy, each type of literacy has been categorised under each of Aring's (2012) four typology areas.

Table 15 – Skills under the Literacy domain with a definition from the literature and classified into Aring's (2012) four typology areas (C – Cultural; Ie – Interpersonal; Ia – Intrapersonal; T – Technical, job specific)

Skill	**Description**	**C**	**Ie**	**Ia**	**T**
Scientific literacy	Ability to use scientific concepts and processes in explaining phenomena and interpreting data and evidence when making personal and collective decisions that affect issues such as those related to the environment, health and technology, as well as participation in civic and cultural affairs and economic productivity (NRC, 1996; OECD, 2017).	✓	✓	✓	✓
Technological literacy	Ability to use, understand and evaluate technology, use technological principles to develop solutions and recognise that society and technology shape one another (International Society for Technology in Education, 2000; International Technology Education Association, 2007; National Assessment Governing Board, 2010).	✓	✓	✓	✓
Engineering literacy	Apply mathematical and scientific principles to design, manufacture, and operate efficient and economical systems for the benefit of society (Accreditation Board for Engineering and Technology, 2010; OECD, 2003b).	✓	✓	✓	✓
Mathematical literacy	Ability to utilise mathematics to solve problems and make decisions within the context of private, occupational and social life and as a reflective citizen (National Council of Teachers of Mathematics, 2000; OECD, 2017).	✓	✓	✓	✓
STEM literacy	Composed of skills, abilities and the integration of concepts and disciplinary practices across science, technology, engineering and mathematics, coupled with associated knowledge and skills, to enable the creation of innovative solutions to complex problem solving as well as evidence-based reasoning within decision-making on societal, economic and personal levels (Bybee, 2016).	✓	✓	✓	✓

Disciplinary skills. The disciplinary skills domain is comprised of a range of skills that are utilised within STEM disciplines specifically. It is a non-exhaustive list that includes a range of disciplinary skills that would be able to be developed within a school context, these include: mathematical skills, scientific skills, programming, design thinking, operations analysis, technology design, systems analysis and evaluation. Many of these come from a synthesis of O*NET's Skills and Abilities, as articulated in Carnevale et al. (2011), though not all. Design thinking was an item included in the DAE (2014) survey that was rated very highly by employers. However, it was not defined apart from being "the ability to pull together cognitive, behavioural, functional and technical skills to develop solutions to meet user needs" (p. 18) and that it was seen to be "critical to the innovation process" (p. 18) – though this description was in the analysis, not the survey instrument itself. Thus, the definition for Design Thinking in Table 16 is drawn from the work of Dym, Agogino, Eris, Frey, and Leifer (2005) who examined engineering design thinking in the context of teaching and learning. Design thinking is noted as a STEM skill by Eppes et al. (2012) and computer skills such as programming are also often referred to when focusing on STEM skills (Aris & Orcos, 2019).

As was done by DAE (2014), the systems analysis and systems evaluation abilities within O*NET were combined and only the technology/engineering dominant skills likely to be able to be developed within schools were maintained. Quality control analysis, operations monitoring, operation and control, equipment maintenance, troubleshooting and repairing were omitted as they are very occupation specific and not typically a focus within schools.

Unsurprisingly, given their classification as disciplinary skills, these were almost exclusively classified as 'technical, job specific' with the exception of design thinking and operational analysis, as these have the potential to require skills from across all of the typologies (Aring, 2012). This is the only domain, with the possible exception of literacy, that Siekmann and Korbel (2016) would associate with STEM skills, though they would refer to them as disciplinary or technical skills.

Table 16 – Skills under the Disciplinary domain with a definition from the literature and classification into Aring's (2012) four typology areas (C – Cultural; Ie – Interpersonal; Ia – Intrapersonal; T – Technical, job specific) (Aring, 2012; Carnevale et al., 2011; DAE, 2014; Dym et al., 2005)

Skill	**Description**	**C**	**Ie**	**Ia**	**T**
Mathematical	The ability to choose the right mathematical methods or formulas to solve a problem as well as the ability to perform mathematical operations quickly and accurately.				✓
Scientific	Using scientific rules and methods (such as forming hypotheses, and collecting and analysing data) to solve problems.				✓
Programming	Writing computer programs for various purposes.				✓
Design thinking	Processes of inquiry and learning performed in a systems context involving tolerance of ambiguity and uncertainty, decision-making, collaboration and communication in the myriad of design languages.	✓	✓	✓	✓
Operations analysis	Analysing needs and product requirements to create a design.	✓	✓	✓	✓
Technology design	Generating or adapting equipment and technology to serve user needs.		✓		✓

Higher order thinking skills. A collection of skills, though by no means an exhaustive list, was identified as being examples of higher order thinking skills. These included: deductive reasoning, inductive reasoning, active learning, critical thinking, complex problem solving, and creative problem solving (Aring, 2012; Carnevale et al., 2011; DAE, 2014). Quantitative reasoning (Eppes et al., 2012), critical thinking (Achat-Mendes, Anfuso, Johnson, Shepler, & Hurst-Kennedy, 2019; Cheng, 2019; Eppes et al., 2012), problem solving (Achat-Mendes et al., 2019; Aris & Orcos, 2019; Cheng, 2019) and creativity (Aris & Orcos, 2019; Cheng, 2019) are all prominent in the conventional literature, supporting the inclusion of these specific skills.

Higher order thinking skills, while certainly not restricted to STEM disciplines or jobs, were identified as being more strongly developed within Australian STEM-trained employees (DAE, 2014). Abilities such as deductive and inductive reasoning, as defined by O*NET in Carnevale et al. (2011), were explicitly included, even though they are arguably important components of the other higher order thinking skills identified within this domain, critical thinking in particular. They were maintained separately because explicit instruction around these ideas in schools may help students to develop the suite of skills that are required for strong development of the other skills of this domain. Furthermore, reasoning skills are specifically discussed within the Critical and Creative Thinking general capability (ACARA, 2012a), which indicates that a focus on developing these skills falls within the purview of Year 7-10 teachers.

Active learning, critical thinking and complex problem solving were all identified as STEM skills by O*NET and featured within the DAE (2014) survey of Australian employers. However, creative problem solving was only included in the latter. It was identified as one of the most highly sought-after skills by employers and thus is included in this list. As DAE (2014) did not provide a definition of this skill, the work of Dumas, Schmidt, and Alexander (2016) pertaining to creative problem solving in engineering design was used to formulate the definition within Table 17.

A number of the applied skills identified in Aring (2012), such as ability to relate specific issues to wider contexts and formulate and check assumptions, as well as creativity and innovation, were seen as underlying the skills already outlined and thus were not included for the sake of brevity. All of the higher order thinking skills were seen as covering the four skills within the typology articulated by Aring (2012).

Table 17 – Skills under the Higher order thinking domain with a definition from the literature and classification into Aring's (2012) four typology areas (C – Cultural; Ie – Interpersonal; Ia – Intrapersonal; T – Technical, job specific) (Aring, 2012; Carnevale et al., 2011; Dumas et al., 2016)

Skill	**Description**	**C**	**Ie**	**Ia**	**T**
Deductive reasoning	The ability to apply general rules to specific problems.	✓	✓	✓	✓
Inductive reasoning	The ability to combine pieces of information to form general rules or conclusions (includes finding a relationship among seemingly unrelated events).	✓	✓	✓	✓
Active learning	Understanding the implications of new information for both current and future problem-solving and decision-making.	✓	✓	✓	✓
Critical thinking	Using logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions, or approaches to problems.	✓	✓	✓	✓
Complex problem solving	Identifying complex problems and reviewing related information to develop and evaluate options and implement solutions.	✓	✓	✓	✓
Creative problem solving	Characterised by divergent thinking (generation of a variety of ideas), strong working memory (to enable simultaneous consideration of many pieces of information) and relational reasoning (the ability to identify meaningful patterns) by way of generating a wide variety of original ideas.	✓	✓	✓	✓

Interpersonal skills. Interpersonal skills, such as communication, team participation and collaboration are another example of skills that may not come immediately to mind as STEM skills, or at least not STEM-specific skills. However, whilst not unique to STEM, these skills are vitally important for success within the workforce, both within and beyond STEM. The argument for their inclusion in a framework of STEM skills is strengthened by more recent peer-reviewed research indicating that these skills are indeed of great importance within STEM (Achat-Mendes et al., 2019; Cheng, 2019; Eppes et al., 2012)

Interpersonal skills were one of the typologies identified by Aring (2012) and thus both communication and collaboration were coded with that typology in addition to any other relevant typologies for the skill in question. Aring (2012) had a separate entry for written and oral communications, though they have been combined here for concision. It was noted in the DAE (2014) employer survey that communication was the skill most notably absent from the list of skills utilised within the survey, thus the inclusion of communication within this framework seeks to rectify that issue. The definition, designed to encompass all forms of communication in a holistic manner, is derived from the work of Jacobson (2009). Communication was recognised as requiring a certain degree of intrapersonal ability as well as technical ability, particularly as the STEM disciplines and their sub-disciplines have a range of unique forms of communication and have to communicate not just within and between their disciplines but also to the wider public.

The other key interpersonal skill appropriate for development in schools from Aring's (2012) list of employability skills was team participation. However, as indicated within the design thinking definition, collaboration is a central to many STEM disciplinary processes, hence it was specifically added to the team participation skill. The definition for team work and collaboration was obtained from the work of A. M. Thomson, Perry, and Miller (2007) on the conceptualisation and measurement of collaboration.

Table 18 – Skills under the Interpersonal domain with a definition from the literature and classification into Aring's (2012) four typology areas (C – Cultural; Ie – Interpersonal; Ia – Intrapersonal; T – Technical, job specific) (Aring, 2012; DAE, 2014; Jacobson, 2009; A. M. Thomson et al., 2007)

Skill	**Description**	**C**	**Ie**	**Ia**	**T**
Communication	The ability to be able to engage effectively in an exchange of ideas, involving the use of appropriate language and conventions for a given context/audience and selection and mastery of an appropriate medium.	✓	✓	✓	✓
Team participation and collaboration	The ability to work effectively towards a common goal within a team that has well defined roles and responsibilities for its members with the collaboration expected to lead to mutual benefits by the achievement of a common goal.	✓	✓		

Intrapersonal skills. Three intrapersonal skills which, like higher order thinking and interpersonal skills, are not unique to STEM yet important within STEM professions were identified: lifelong learning; self-motivation, initiative and the ability to work independently; and time management. These skills have also been noted within the conventional literature as being important for success within STEM, motivation in particular (Achat-Mendes et al., 2019; Aris & Orcos, 2019).

Intrapersonal along with interpersonal was a typology in the work of Aring (2012) and thus each of these have been coded as interpersonal, as well as other relevant typologies on the basis of the definitions of each of these skills.

After being originally conceived in 1969, lifelong learning has been said to be "the most important educational paradigm of our times" (Ohidy, 2008, p. 17). It is a cognitive process, involving formal, non-formal and informal learning, from early childhood right through to late old age. Given its strong importance within an ever changing world, it is interesting that employers placed a relative lack of importance on this particular skill (Table 13), with the exception of Education and Training. Lifelong learning has gained increasing focus of late, including within the STEM field, as indicated by its inclusion in the DAE (2014) employer survey. This is perhaps a result of the belief that such an approach to learning can assist in managing a life filled with political, social and economic change (Ohidy, 2008). The definition included in Table 19 is based on the work of Ohidy (2008) though it has been adjusted to reflect the fact that high school[18] lasts a mere four years during a person's adolescence, thus it is more a mindset to be cultivated rather than a skill that students can be expected to have developed to a large extent. As the type of learning is not confined to any particular area, it has been categorised across all typologies, though it is classified ultimately as an intrapersonal skill as it is one the individual must ultimately develop and maintain for themselves.

Self-motivation, initiative and the ability to work independently is a combination of a few of the employability skills within Aring's (2012) work and thus has been classified as having some technical, job specific characteristics as well as its overarching intrapersonal nature. Within the context of schooling, the development of these skills are related greatly to the concept of self-directed learning, which is characterised by the individual setting their own goals, identifying the human and material resources they will need in working towards their goals, utilising learning strategies that are most effective for them, and evaluating their own learning outcomes (Loyens, Magda, & Rikers, 2008). A key goal for teachers is to develop these self-directed learning skills in their students so that they can take an increasing amount of responsibility for their learning throughout their schooling such that they are well set-up to continue to engage in lifelong learning post formal education. Invariably, some parts of almost all tasks someone must perform at school, as well as in their occupation and life more generally, will involve boring or difficult components which, nevertheless, must be completed. A person's ability to persevere and perform well at these times is associated with their ability to motivate themselves. Self-motivation "develops during childhood as a function of internalising encouragement received from significant others when encountering difficult or unpleasant tasks" (Kazén, Kuhl, & Leicht, 2015, p. 1064). Throughout a person's childhood and adolescence, teachers are very significant others and thus the cultivation of self-motivation is another task that falls within the scope of a teacher's role in preparing their students for their lives after school. These ideas were taken together to create the definition in Table 19.

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[18] Taken here to mean Years 7-10 only.

Time management was included within the DAE (2014) survey alone of the sources examined within this section, however, it is an important skill that people should cultivate as early as possible. High school provides an ideal opportunity for continued scaffolded development of time management skills within students so that they can come to recognise that time is a valuable resource. The definition provided in Table 19 was derived from the work of Zimmerman, Bonner, and Kovach (1996) who discussed how to develop self-regulation, self-monitoring and self-efficacy in learners such that they could make accurate judgments about their learning methods and identify how to improve. It has been categorised predominantly as an intrapersonal skill as it is mainly dependant on the self. However, depending on the tasks to be managed, it may have interactions with the other skill typologies.

Table 19 – Skills under the Intrapersonal domain with a definition from the literature and classification into Aring’s (2012) four typology areas (C – Cultural; Ie – Interpersonal; Ia – Intrapersonal; T – Technical, job specific) (DAE, 2012; Deloitte Access Economics, 2014; Kazén et al., 2015; Loyens et al., 2008; Ohidy, 2008; Zimmerman et al., 1996)

Skill	**Description**	**C**	**Ie**	**Ia**	**T**
Lifelong learning	Development of a love of learning and an awareness of the most personally effective learning strategies to enable continued learning in different contexts throughout life.	✓	✓	✓	✓
Self-motivation, initiative and the ability to work independently	The ability to set goals, identify and utilise required resources and apply personally effective strategies to obtain the desired outcomes, motivating one’s self as required, particularly when faced with difficult and/or boring tasks.			✓	✓
Time management	The ability to self-regulate and self-monitor the use of one’s time by setting realistic goals, identifying optimal working environments and how to avoid distractions, prioritising tasks and self-rewarding success.	✓	✓	✓	✓

Final notes on STEM Skills that can be developed within Schools

The knowledge domain from Carnevale et al.’s (2011) study, Table 7, was omitted as it focuses far more on content knowledge than skills. However, it was included in the previous section as it demonstrates the context in which skills can start to be developed within schools. The remaining skills from Carnevale et al.’s list (Table 8), i.e. from quality control analysis to repairing, are unlikely to be developed substantially within school and so were omitted. It is possible that Australian students may get a degree of exposure from the Technologies learning area, but any genuine development of skill in this area is more likely to come from vocational work experience placements or ASbAs. The remaining abilities from Table 9 were either incorporated into a more holistic skills (e.g. number facility into numeracy), or are unlikely to be developed to a significant extent in school. Finally, the remaining skills in Aring's (2012) list (Table 11) and those from DAE's (2014) survey (Table 12) were more occupational than school-level in nature. It is worth noting that each of the skill typologies as defined by Aring (2012) are represented almost equally and that most skills have been categorised as covering at least two skills areas. Difficulties were noted by the employers who participated in Aring's (2012) study regarding teaching cultural, interpersonal and intrapersonal skills. Early and regular use of these skills within schooling can presumably only help by providing students with multiple opportunities to develop skills in these areas before they enter the workforce.

Taking each of the domains that have just been presented, an overview of STEM skills that are suitable for development within high schools is shown in Figure 7.

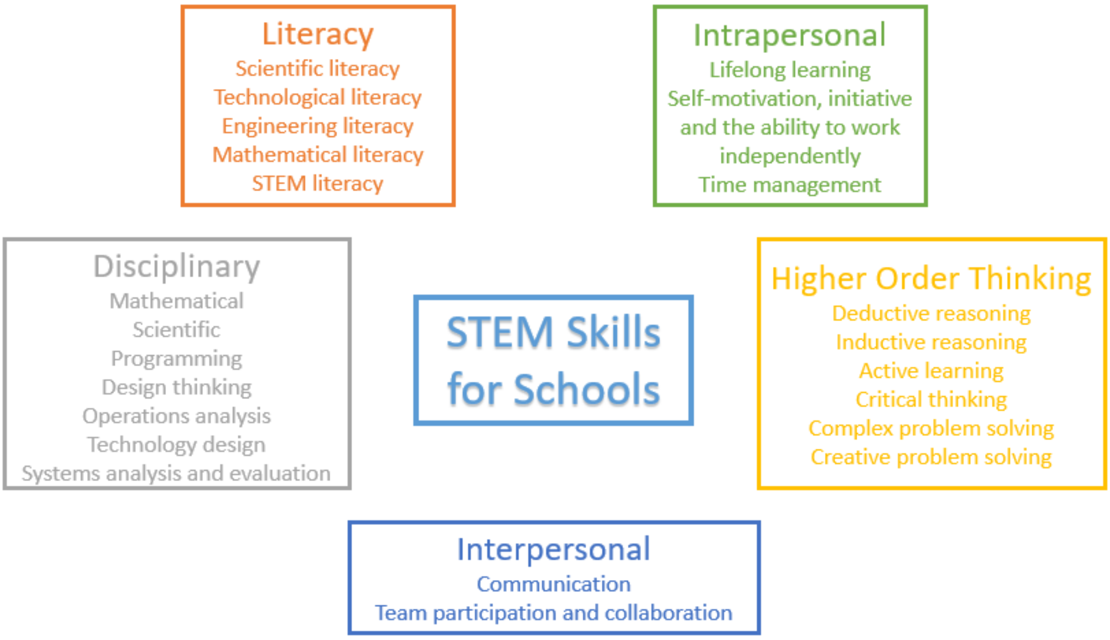

Figure 7 – STEM Skills suitable for development within high schools (Aring, 2012; Carnevale et al., 2011; DAE, 2014)

Skills within the literacy and disciplinary domains are quite specific to STEM and are most likely to be developed within STEM disciplines and be required predominantly within STEM professions. The other three domains, higher order thinking, interpersonal, and intrapersonal skills, are by no means specific to STEM disciplines or professions. However, they may be developed within STEM disciplines and are important within STEM professions. Each of these skills can be developed within a high school context.

This concludes Part 1a, as a definition of STEM skills taken from the literature, with a focus on those that may be developed within Years 7-10, has been made. The focus in Part 1b shifts to the perspectives of Australian high school STEM teachers on the notion of STEM skills.

Research Question 1b – What are STEM skills according to Australian Year 7-10 STEM teachers?

This section presents an analysis and interpretation of the responses from the survey of Australian Year 7-10 teachers. Teachers from all Australian states and territories were included and all sectors (government, independent and Catholic) were represented. The first section examines the demographics of the respondents and their schools so that the demographics of the survey participants could be compared with national data. Comparisons between the survey and the teaching population were performed to determine how representative the survey sample is of the Australian teaching population. This is followed by an analysis of the proportion of respondents who had heard the phrase 'STEM skills', and through what means, to determine the familiarity of respondents with the concept. The key component of this section is an examination of what teachers associate with the phrase STEM skills. Their responses were coded inductively so that they can be compared with the skills that emerged from the literature articulated in Part 1.

Section 1 – Demographics of the respondents and their school

A total of 217 respondents responded to the survey, of which 145 responses were retained for analysis. Responses that were incomplete, answered by non-Australians or by teachers working as relief staff[19] were excluded. The latter were removed because a working knowledge of the day-to-day implementation of the Australian Curriculum was required for a component of the survey which is analysed in Chapter 6.

Biological Sex. The majority of respondents were female (69%) which represents a skew towards females that is more pronounced than that of the TALIS 2013 survey which indicated that 59.2% of Australian teachers were female (Freeman et al., 2014). Males are therefore slightly underrepresented in this study. A key limitation in this comparison is that respondents of the survey were Year 7-10 STEM teachers whereas those from the TALIS 2013 survey were representative of Australian Year 7-10 teachers of any discipline. Unfortunately, data regarding gender break down within Australian STEM teachers was unable to be obtained. However, it is a well-known problem that Australia has a chronic shortage of male teachers, within primary schools in particular, where the proportion of male teachers is significantly lower. However, the overall trend is a worrisome downwards trajectory for males in secondary as well as primary school teaching (McGrath & van Bergen, 2017). Thus, while it is noted that the percentage of female respondents is arguably a little high, it is unlikely to have a dramatic effect on the results because the trend is for an increased percentage of female teachers within Australia. The TALIS 2013 report is based on data collected five

[19] Relief staff, also known as supply staff or substitute teachers teach for another teacher if they are away for any reason, generally just for a day at a time and thus are not responsible for lesson preparation and so on.

years prior the data collection of this study and thus the proportion of females is expected to have increased during this time interval.

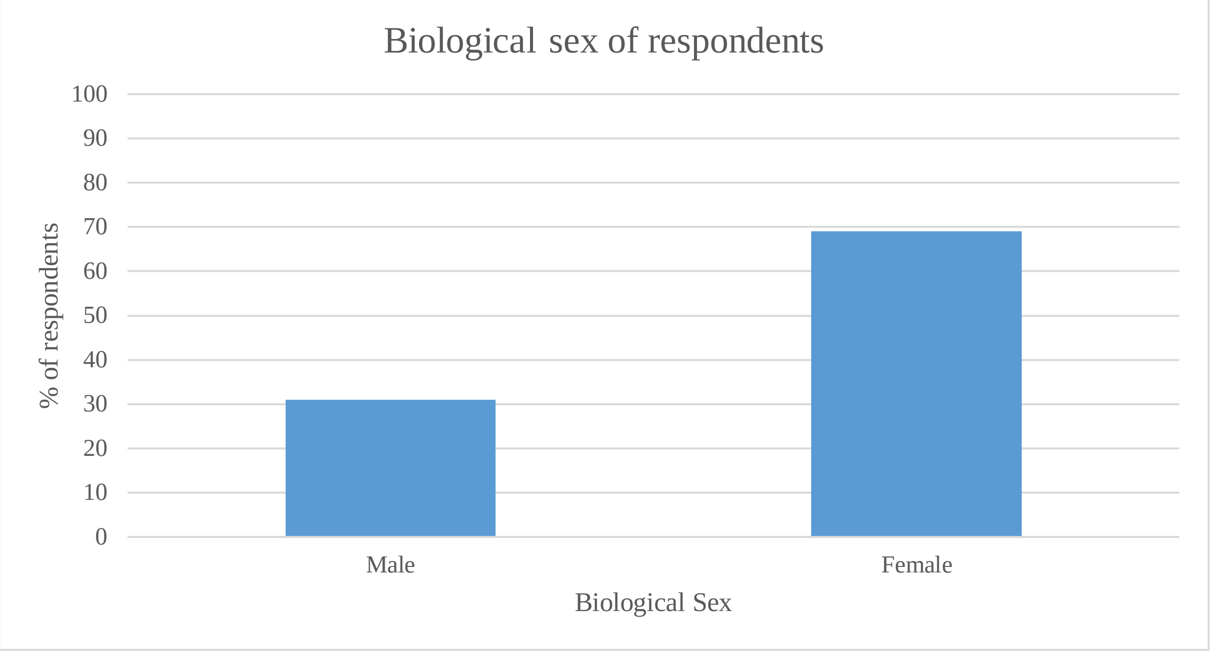

Figure 8 – Biological sex of respondents (n = 145)

Age. The age distribution of respondents can be seen in Figure 9:

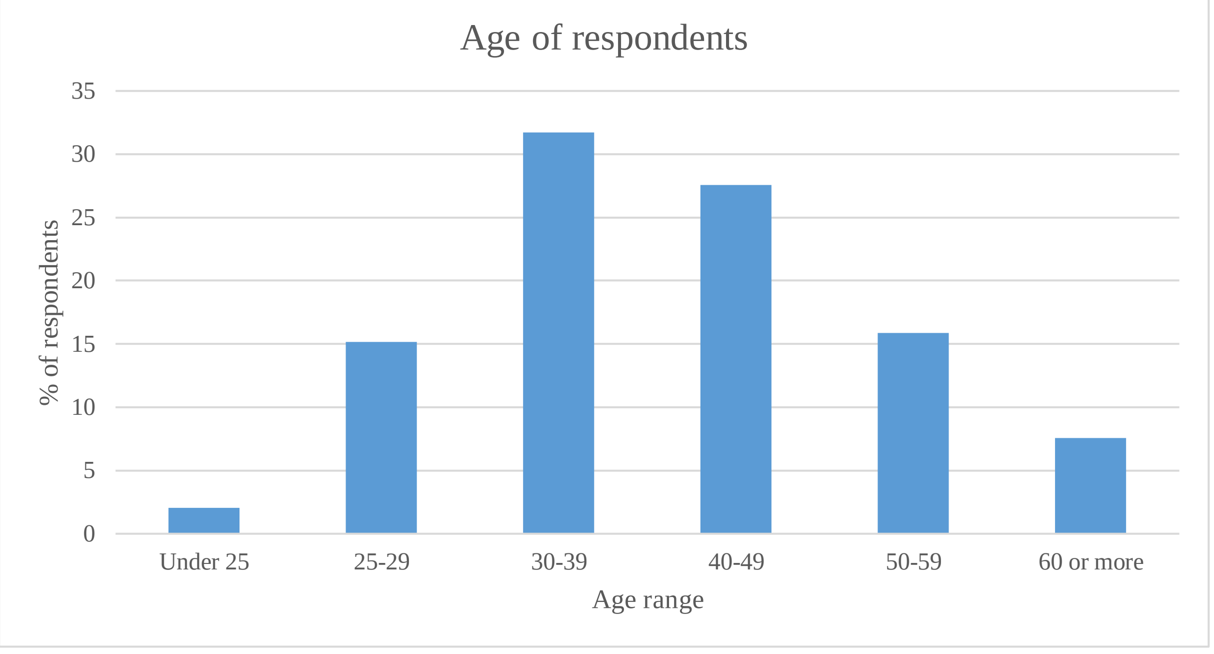

Figure 9 – Age of respondents (n = 145)

It can be seen in Figure 9 that there is an approximately normal distribution of ages for the categories which were provided. Table 20 shows a comparison between age information obtained through TALIS 2013 and the STEM skills survey.

Table 20 – Comparison of data pertaining to the age of Australian teachers from TALIS 2013 (Freeman et al., 2014) vs. the STEM Skills Survey

	TALIS 2013	STEM Skills Survey
Average age (in years)	43.4	41.5[20]
Proportion of teachers over 50 (%)	37.1%	23.4%
Proportion of teachers under 30 (%)	15.7%	17.2%

Table 20 shows there are some disparities between the ages of Australian teachers participating in TALIS 2013 versus those who completed the survey. Overall, teachers completing the survey were slightly younger than the national average, with fewer teachers over 50 and more teachers under 30 than was the case for the TALIS 2013 survey. A potential reason for this is that a primary distribution channel for the survey was via social media, and that younger teachers are therefore more likely to have encountered the survey than their older colleagues.

Years spent teaching. While it might be expected that the distribution of years spent teaching would follow a similar trend to the age distribution of teachers themselves, Figure 10 shows that this is not the case.

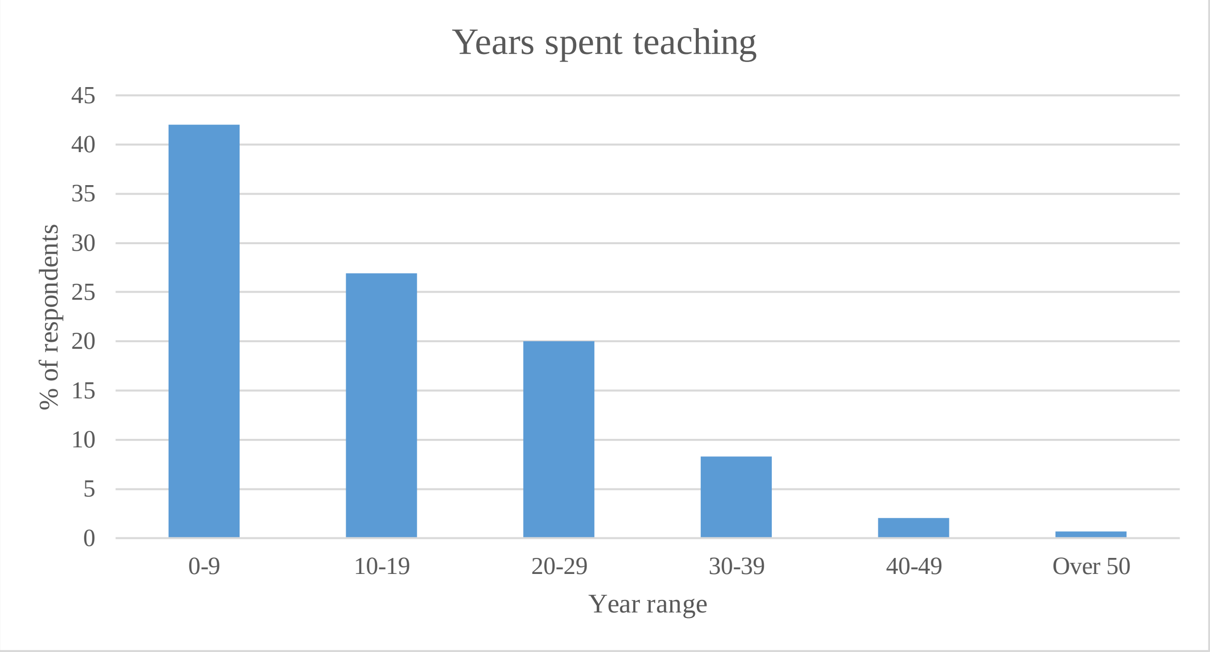

Figure 10 – Distribution of number of years spent teaching (n = 145)

Figure 10 shows a pattern that is almost an exponential decay of years spent in teaching. This is in line with the narrative that teachers have left and continue to leave teaching in droves. Up to 20%

[20] As respondents were given age ranges from which to choose, the calculation of an average was based upon the assumption that 'Under 25' represented ages 20-24 and that '60 or more' represented ages 60-69. An average was calculated using the centre of each age bracket and the frequency with which that age bracket was selected.

of Australians with a teaching qualification do not even register as teachers upon graduation. A further 53% of people who hold a teaching degree are not currently working within education (Stroud, 2017).

Highest qualification. The highest qualification of teachers completing the survey is shown in Figure 11.

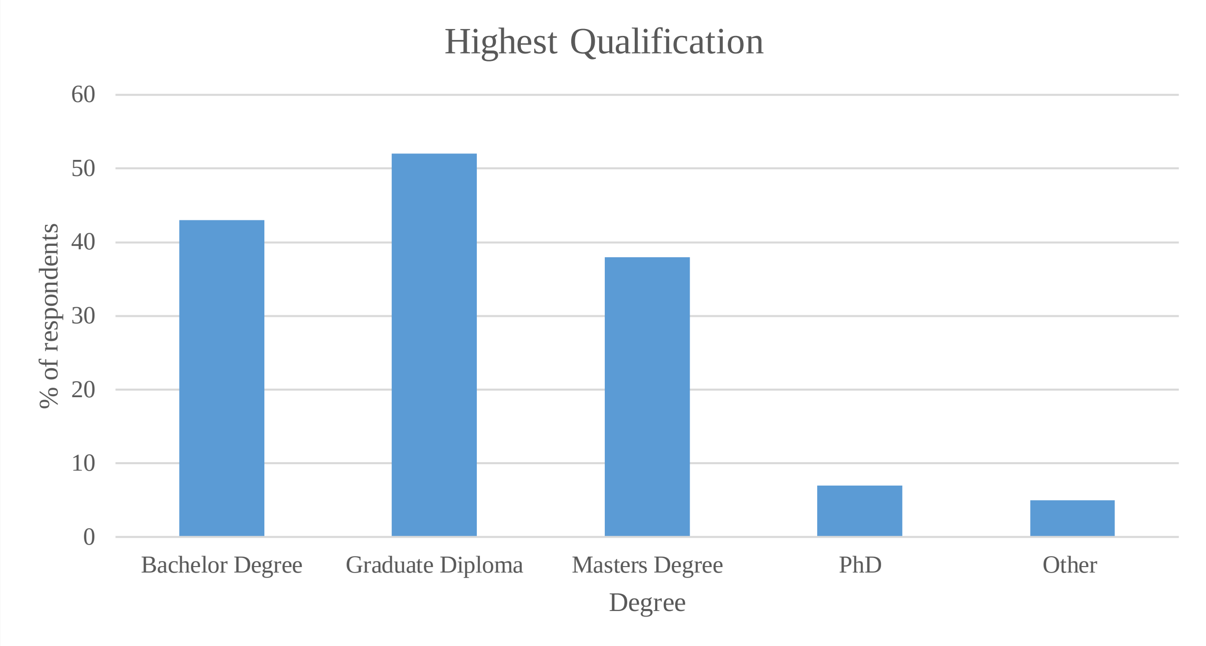

Figure 11 – Highest qualification obtained by teachers who completed the survey (n = 145)

The ‘other’ category included responses such as a Bachelor’s degree with Honours or a Graduate Certificate. Respondents to the survey are thus typical in that “virtually 100% of the Australian teaching workforce hold a qualification at ISCED level 5A (undergraduate and postgraduate diploma or degree), or above” (Freeman et al., 2014, p. xiii).

In or out-of-area. Respondents predominantly (88%) considered themselves to be teaching ‘in area’, that is, teaching subjects for which they are qualified. This leaves approximately 12% of teachers who consider themselves to be ‘out-of-area’ (no formal training in a subject they are teaching). This is higher than the figures given by TALIS 2013 for mathematics (5.3%) and science (5.6%) (Freeman et al., 2014). In an address given at the conference of the Australian Science Teachers Association in 2018, then Minister for Education and Training, Senator Birmingham, said “In 2013, it was estimated that around 20 per cent of general science teachers taking Year 7-10 classes had not completed at least one year of tertiary study in that area” (Birmingham, 2018). Where Senator Birmingham took this figure from is unknown as it is quite different from the percentages provided from the TALIS survey, also released in 2013. It has been extrapolated in numerous publications to suggest that “20% of STEM teachers are teaching outside their area of expertise” (Science & Technology Australia, 2018) or “about 20 per cent of STEM teachers do not have the appropriate subject qualifications" (Brown, 2018). Generally this has focused on mathematics and science teachers (Beech, 2018; Crook, 2018). The OCS cited *Profiles of Teachers in Selected Curriculum Areas: Further Analyses of the Staff in Australia's Schools 2013 Survey* by ACER in suggesting that "around 20% of secondary maths and science teachers across all sectors (government, independent and Catholic) are teaching 'out of field'" (OCS, 2017, para. 6).

It is unclear therefore exactly how many teachers are teaching out-of-area within STEM as there are no recent reports that analyse out-of-field teachers for all STEM disciplines. However, it has been the narrative for quite some time that within Australia that there is an insufficient number of trained STEM teachers (Timms et al., 2018).

Information regarding the demographics of the respondents' schools was also obtained. This included the state/territory of the school and its sector. This data was obtained to determine the degree to which the make-up of schools represented by respondents mirrored the distribution of Australian schools.

Geographic location of the school. Unfortunately, due to the large inconsistencies in approvals between states and territories and each sector that exist within Australia at present for conducting research involving teachers, distribution channels across the different states/territories and sectors of schools varied greatly. As a result, the proportion of respondents from each state/territory/sector are not representative of the natural breakdown across Australia.

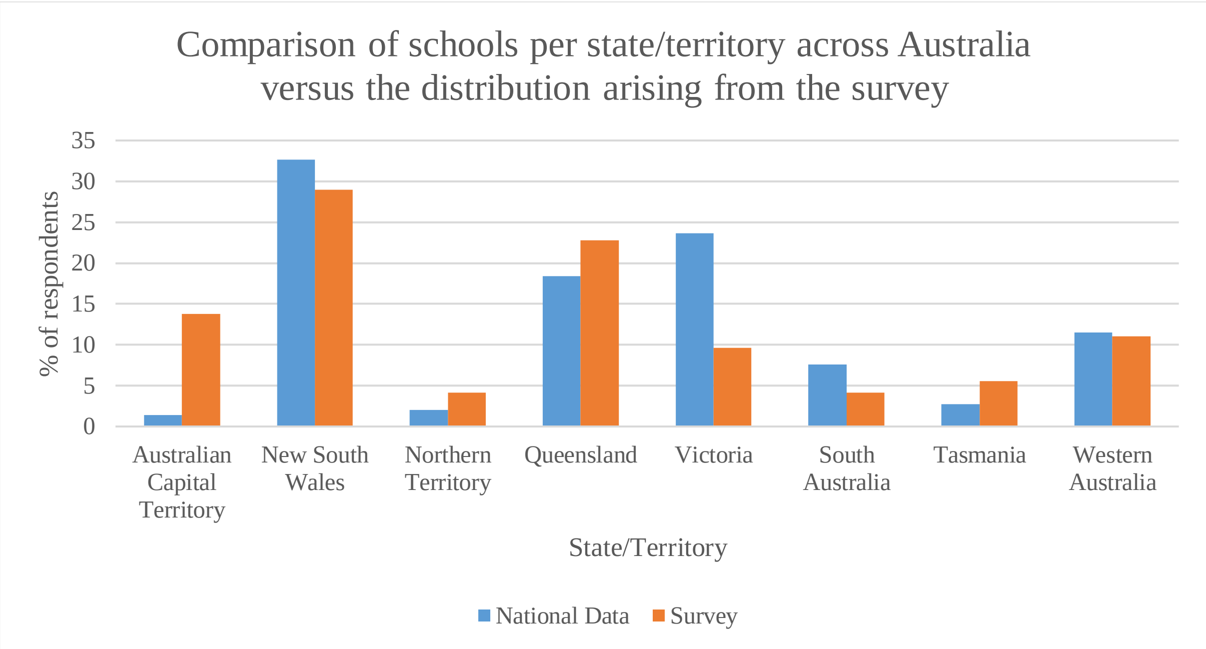

Figure 12 – Breakdown of proportion of Australian schools in each state/territory (n = 9444) (ABS, 2018c) versus proportion of schools described in the survey (n = 145)

It is observable that there is a large overrepresentation of schools from the Australian Capital Territory and an underrepresentation of schools from Victoria. Other states/territories demonstrated relatively similar percentages.

School sector. There were also profound differences in the approvals processes for each sector which typically varied across the different states and territories. The breakdown by sector is shown in Figure 13.

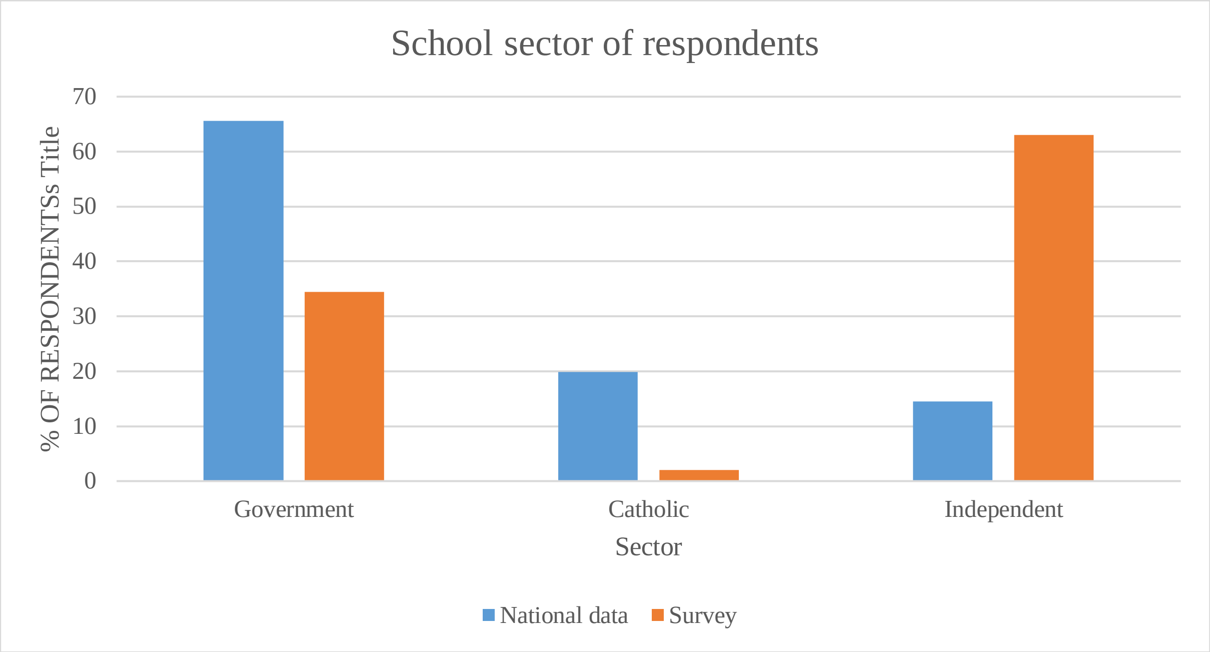

Figure 13 – Schooling sector breakdowns across Australia (ABS, 2018b) (n = 9444) of survey respondents (n = 145)

There is a very evident overrepresentation of independent schools and an underrepresentation of government and catholic schools within the survey. This is largely due to sampling issues, which made it difficult, and in some cases impossible, to obtain data from some sectors in some states and territories. As independent schools are autonomous, they were all able to be contacted directly by the researcher and invited to participate. This may have contributed to their overrepresentation.

Overall, the analysis of the demographics of respondents indicated that, with the exception of the state/territory and sector from which they come, the teachers who completed the survey are quite representative of Australia's teaching population. The differences in the state/territory and sector from which respondents were drawn, compared with national data, unfortunately was due to sampling issues that are a result of the lack of uniformity across Australia in terms of how educational research is to be conducted and how teachers may be recruited to participate.

Section 2 – Awareness of the phrase 'STEM skills'

In response to the question "*Have you heard the phrase 'STEM skills' prior to this survey?*", 97% responded 'Yes', while only 2% said 'No' and 1% were 'Not sure'. This indicates that people who chose to respond to the survey are on the whole aware of STEM and the notion of STEM skills. As a result, this data cannot be used as an estimate for the general level of familiarity of Australian teachers with the concept 'STEM skills'. However, it can provide useful information regarding the most common avenues through which Australian STEM teachers hear about STEM skills.

Figure 14 depicts the proportion of respondents who had heard of STEM skills through a variety of different means. Respondents could select as many as were appropriate.

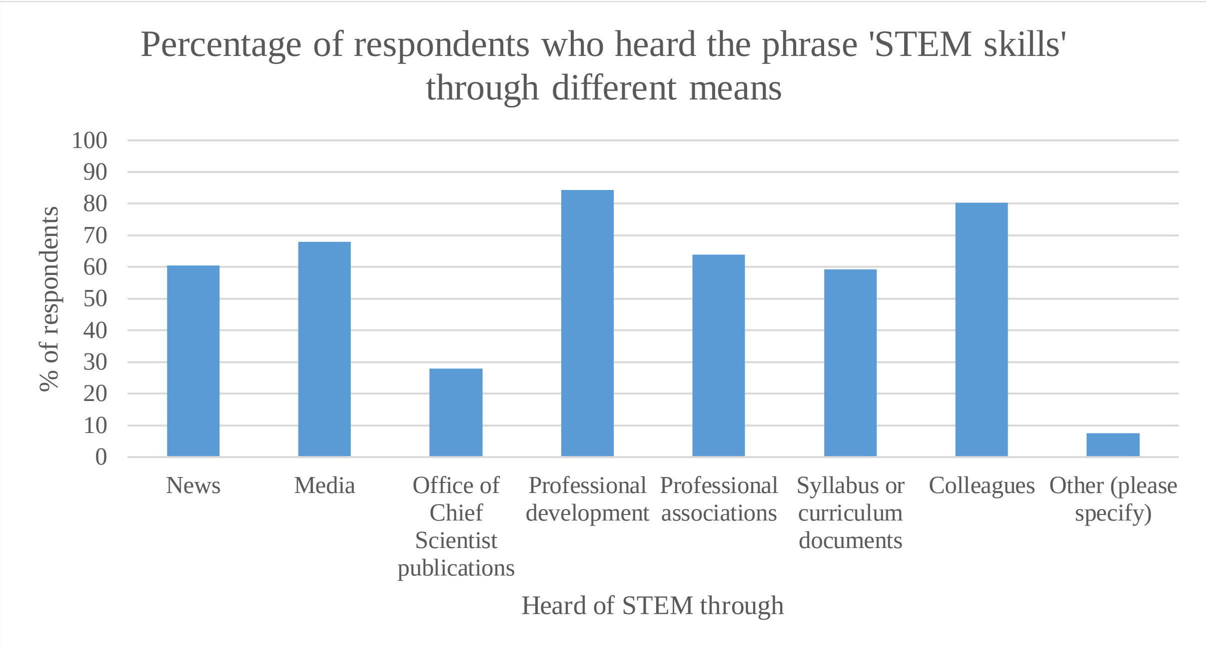

Figure 14 – Percentage of respondents who heard the phrase 'STEM skills' through different means (n = 145)

The most common route of exposure to the notion of STEM skills was professional development, with 84% of respondents indicating that they had heard of STEM skills via this route. Almost everyone who responded to this section of the survey had heard of the phrase through multiple avenues. The large focus on STEM in professional development and the fact that teachers are encountering the concept of STEM skills through multiple avenues verifies that STEM is currently a large focus within education, for teachers of the associated disciplines at any rate.

Section 3 – What are STEM skills according to Australian teachers?

In this section of the survey, teachers were asked to list five to ten things that they associate with the phrase STEM skills. The 145 respondents collectively listed 850 responses at an average of 5.86 responses each. Once responses that contained multiple distinct ideas were separated into individual listings the total number of responses increased to 894 at an average of 6.17 responses per respondent.

Upon entering the raw data into WordClouds.com two versions of word clouds representing the data were generated and are shown in Figure 15 and Figure 16.

Figure 15 – Data entered straight into WordCloud.com

Figure 15 shows all entries that were listed by three or more individuals. It is evident from this word cloud that, when asked about STEM skills, problem solving is the overwhelming response. As problem solving was such a dominate response, somewhat masking the other skills that were listed, Figure 16 was created. It lists the same data following the removal of problem solving so that other frequently listed skills could more readily be observed.

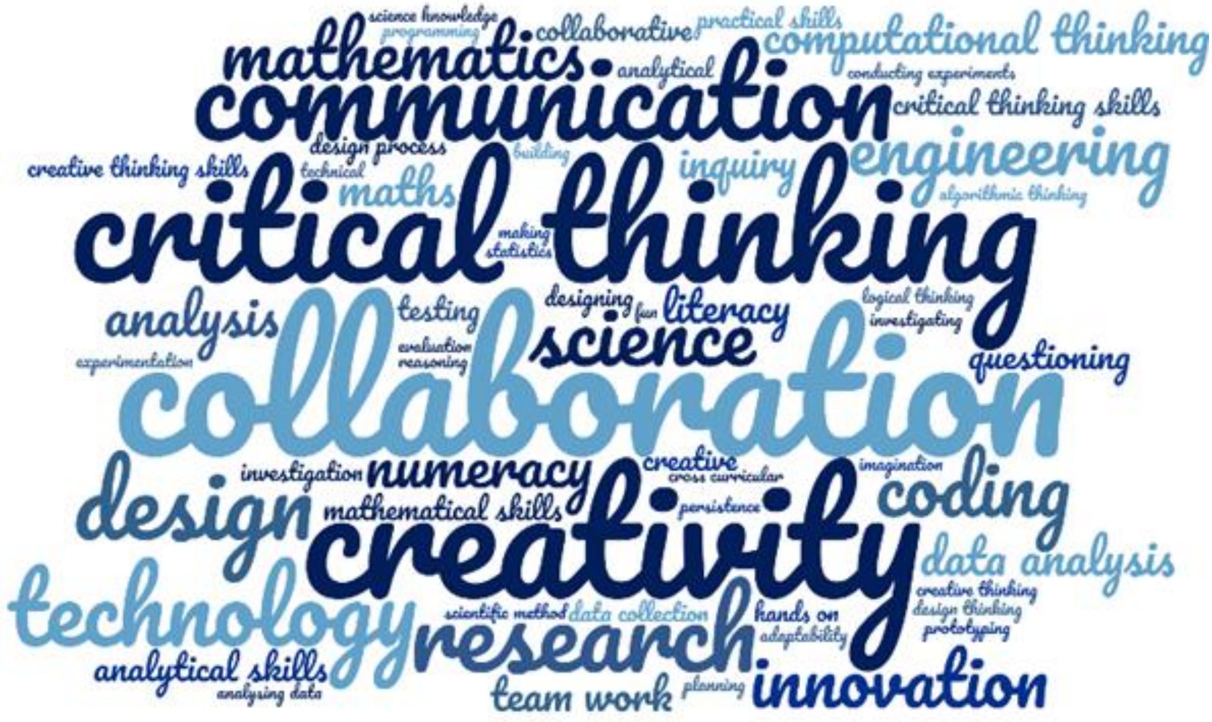

Figure 16 – Data entered into WordCloud.com with the exclusion of problem solving

Collaboration, communication, creativity and critical thinking are all stand-outs from Figure 16. Each of these were also identified from the literature. A close look at Figure 16 shows that teachers identified a wide range of things within the phrase 'STEM skills'. It was noted that, despite being asked about STEM *skills*, many responses did not list skills but rather things related to STEM. For example, they listed the names of disciplines, approaches to teaching STEM and catch-phrases.

By way of extracting useful information from this list of responses, each response was sorted into categories in an inductive manner. Most of the responses fell into a distinct category with approximately 40% of responses falling into two or more categories. The final categories used for classification, and the number of responses within each, are shown in Figure 17.

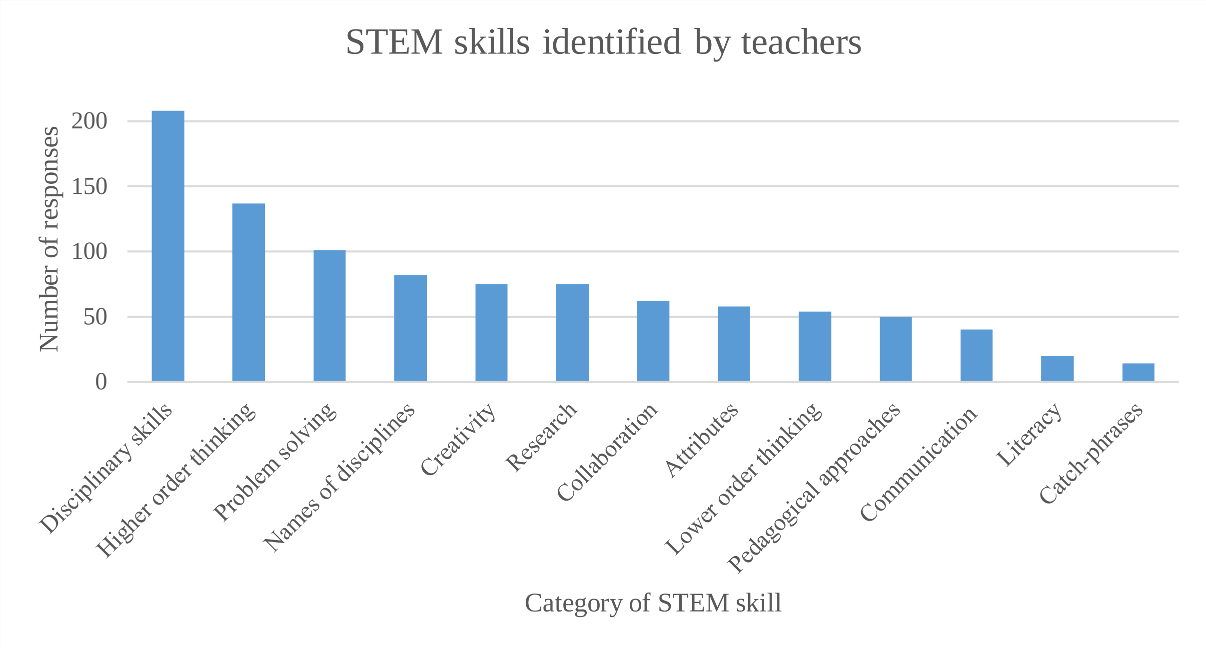

Figure 17 – Categories which emerged from the data and the number of responses for each (n = 894)

It is important to note that the sheer number of responses that pertained to problem solving was such that these responses were put into a separate category for ease of analysis. However, it is acknowledged that problem solving is a higher order thinking skill and that when these two sections are combined, higher order thinking has the highest overall response rate. Creativity further enhances the higher order thinking response rate but was also separated to examine responses pertaining to creativity specifically. Some examples of the types of skills given within each category will now be provided in reverse order of rate of response.

Perhaps due to the many and varied means by which teachers encounter the notion of STEM skills, as demonstrated in Figure 14, a number of catch-phrases rather than skills were listed. Future and 21st century skills were prevalent. This is little surprise given that the focus on STEM and STEM skills is largely discussed in the context of these being the skills people will need for the jobs of the future, including those which do not currently exist (Australian Academy of Science, 2019; Marginson et al., 2013). Industry skills were also mentioned which is perhaps a reflection of the focus on STEM across a wide variety of industries and the strong representation of the VET sector within Australia's STEM workforce (Baranyai et al., 2016; Siekmann & Korbel, 2016).

Interestingly, only 2% of respondents referred to some form of literacy and, in most instances, they referred to literacy in general. Some mentions were made of disciplinary specific literacies, technological literacy predominantly. Thus, the importance of STEM literacy for all students, as put forth by Bybee (2016) and Zollman (2012), does not appear to be shared by Australian STEM teachers.

Similarly, many responses that were classified as pertaining to communication merely listed the word ‘communication’. However, there were some responses in which more specific forms of communication were provided, for example: written communication; communication via visual and/or multimedia formats; composing a literature review; and rationalising arguments. All of these forms of communication remain applicable to any discipline.

A range of responses that were not anticipated pertained to pedagogical approaches utilised in teaching STEM. For example, multiple references were made to the interdisciplinary/cross-curricular nature of STEM along with getting students to work in groups to complete projects. There are some strong arguments for the integration of STEM subjects (Berry et al., 2012; Johnson, 2013). However, it is not something that teachers are necessarily used to, especially within a Year 7-10 context in which subjects are typically taught in quite a siloed manner (Herschbach, 2011).

Lower order thinking skills were mentioned at a much lower rate than higher order thinking skills. Responses tended to fall into knowledge, application and understanding. In terms of knowledge, references were made to specific content within any of the STEM learning areas. Other responses alluded to the ability to take knowledge and apply it within a different context, whether that be another subject area (such as applying mathematics in science), to an interdisciplinary context, or to the solving of a problem. Finally, the importance of understanding certain concepts of the STEM disciplines themselves was highlighted.

Approximately 6% of responses pertained to personal attributes, particularly how people approach challenging situations, rather than skills per se. A little over half of these responses were focused on qualities such as curiosity and a questioning attitude, having an enterprising nature, and the organisation and motivation needed to approach problems. The adaptability and flexibility needed to take prior knowledge and skills and apply them to problems in new contexts were also noted. The other group of responses dealt with how people respond to dealing with failure and/or the willingness to take risks. This was associated with the need for strong self-esteem, resilience and a growth mindset as well as the ability to work effectively independently or collaboratively. There was some overlap between the attributes listed and the dispositions that were identified in state/territory STEM strategy documents (Table 2). Collectively, this group of responses outlines attributes that any employer would desire within a potential employee. They are by no means unique to the STEM disciplines. Nor are these skills only developed within STEM subjects at school. Thus, their association with ‘STEM skills’ specifically is interesting. Those pertaining to concepts such as self-esteem and a growth mindset possibly reflect the increasing focus on wellbeing within schools (Australian Catholic University and Erebus International, 2008; Waters, 2016) rather than them being essential qualities for STEM as such.

Collaboration, or synonyms such as teamwork or group, along with the ability to build and lead teams of people were identified by 7% of respondents. This is perhaps due to the large focus placed on group work within STEM education. For example, it is one of the capabilities listed in various state/territory STEM strategies (Murphy et al., 2019). The context of solving real-world problems is frequently used as a way in which to teach STEM and this almost always requires collaboration (Berry et al., 2012).

As for communication, the 8% of responses pertaining to research was split between referring to research quite generically through various synonyms, and referring to very disciplinary specific forms of research. Of the latter they were mainly focused upon research undertaken within science. The responses that were categorised within research referred to steps in a research process such as questioning or discovery. These responses all fit the paradigm that learning in STEM often involves some form of project-based learning through long-term projects or investigations (Berry et al., 2012).

Approximately a third of the responses simply listed creativity, creative or creating, with some others expanding slightly to creative thinking. A little over a quarter of responses tapped more specifically into innovation. Innovation is closely aligned with creativity, but is focused more towards developing an appropriate solution for a problem than generating a range of solutions without necessarily considering their feasibility (Marshall, 2013). The remaining responses covered a range of ideas related to creativity such as imagination, invention, lateral thinking and the manipulation of ideas. It is interesting that creativity was so frequently noted within a question about STEM, rather than STEAM, as the creativity aspect of the Arts is often the argument used for the inclusion of the Arts (Jolly, 2014). This perhaps reflects that teachers within STEM appreciate the importance of creativity within each of these disciplines. Or it may mean that these teachers are responding with respect to STEAM rather than STEM, possibly due to the focus within their school being on the former.

Surprisingly, 9% of responses simply stated the name of a discipline despite being asked about STEM *skills*. While the overwhelming number of these responses did at least refer to a STEM discipline, or a sub-topic such as algebra, there was also at least one mention of art, business, economics and English, which is quite perplexing. In terms of the STEM disciplines themselves, technology was mentioned most frequently, followed by mathematics and science at roughly the same rate, and finally engineering. The low rank of engineering is perhaps in part because it is not generally taught within Australian schools.

The majority of the 11% of responses within the problem solving category were stated as such, a few mentioned problem finding. The remaining quarter of responses alluded to the frame of mind required to solve problems, the use of STEM disciplines to solve problems, or the real-world nature of the problems students often solve within STEM. This focus upon problem solving within the context of real-world scenarios ties back to the concept of developing skills for the future and the argument that STEM disciplines help to develop the skills required to solve the problems of today and tomorrow (Timms et al., 2018).

After the removal of creativity and problem solving from the higher order thinking category, 15% of responses still pertained to this category. The range of responses was quite general, in decreasing order of frequency were terms such as critical thinking, analysis, evaluation, higher order thinking, logical thinking, deduction, interpretation and justification of ideas. Responses tied more strongly to a particular discipline included computational thinking and algorithmic thinking for technology; data analysis, including extrapolation and interpretation within science; and the ability to reason mathematically and recognise patterns and trends featured for mathematics.

The final category with 23% of the responses, pertained to disciplinary skills not already covered within an aforementioned category. The first set of skills within this category will be described in terms of the discipline to which they belong. The remaining responses were not clearly linked to one STEM discipline but could apply to multiple contexts. Relatively few responses pertained to mathematics specifically but those that did pertained to numeracy, mathematical skills, being able to perform calculations and make measurements. The science skills focused on skills related to experimentation with approximately half pertaining to conducting experiments or field investigations. The other half focused on making hypotheses, following the scientific method, and the use of qualitative and quantitative observational skills. In terms of technology, coding and programming predominated. However, robotics, using software, computer-based design and manufacturing and the use of technology to represent data and solve problems all featured. The engineering skills focused on design thinking or the design process and being able to use appropriate materials and tools to construct a design that suited market needs. The more generic disciplinary skills were listed as technical/industry/disciplinary skills, planning, questioning, modelling, predicting, producing, project management, testing and working systematically. This group of skills, that collectively made up approximately a quarter of all responses, are perhaps the skills that one could most reasonably argue are typical of STEM disciplines more so than any other discipline and are therefore most easily classified under the banner of STEM skills.

It is clear to see that the phrase ‘STEM skills’ has been interpreted by responding teachers to mean a myriad of things. Disciplinary skills and the mere listing of STEM disciplines, which made up 32% of responses, were clearly related to STEM disciplines specifically. However, the remaining 68% of responses referred to skills that are by no means unique to STEM. All disciplines require students to develop and demonstrate a range of lower and higher order thinking skills as well as research, problem-solving, creativity, collaboration and effective communication. The attributes listed would be wished for by any employer. Pedagogical approaches utilised within STEM would also be appropriate in other disciplines. Whilst certainly developed within STEM disciplines and required by STEM jobs, most of the skills listed by teachers are ubiquitous.

Research Question 1c – How do the perspectives on STEM skills from the literature and Australian Year 7-10 STE teachers compare?

The five domains of STEM skills articulated at the end of Part 1a of this chapter, and the skills listed as examples within each, will form the basis for the comparison of the literature and teacher perspectives on STEM skills.

Literacy

The literacy domain in the framework, comprised of the four individual disciplinary literacies as well as STEM literacy, was included despite the relatively low degree of focus placed upon literacy within the four reports examined in Part 1. While Aring (2012) included a couple of references to literacy in general as well as specific types of literacy, no other report included it. In this respect, the reports used in this chapter and the respondents of the survey are in agreement, with a mere 2% of teacher responses falling into this category. However, this is a cause for concern. One of the key arguments for a focus on STEM, as presented in Chapter 3, is the need for all students to be STEM literate, regardless of whether they intend to pursue a career in STEM (Bybee, 2016; Salzman & Benderley, 2019). Additionally, results in PISA, which predominantly seeks to assess students' disciplinary literacy skills, are repeatedly used by policymakers as a metric for Australian students' performance in STEM compared with that of their international peers (OCS, 2013a, 2014a; Salzman & Benderley, 2019). The extent to which PISA assesses mathematical and scientific literacy will be examined in Chapter 7. However, given it is one of the most frequently used metrics and focuses on *disciplinary literacies*¸ it is somewhat intriguing that neither the literature presented in this chapter, nor Australian teachers who participated in the survey, place any significance or importance upon it.

Disciplinary

Disciplinary skills were a key focus in the work of Carnevale et al. (2011) and are akin to one of the four typologies used by Aring (2012) – technical or job specific. This strong focus on the two primary reports used in generating the skills list featured within the DAE (2014) survey is reflected with the presence of some specific disciplinary skills as well as the generalised occupation-specific STEM skills option. Finally, Siekmann and Korbel (2016) argued the point that technical skills are in fact all that ought to be considered within the phrase STEM skills. Thus, the focus in the literature upon STEM-specific disciplinary skills was very strong. Likewise, respondents to the survey placed a strong focus on disciplinary skills. This category placed second overall (when creativity and problem solving were re-absorbed into higher order thinking), accounting for 23% of the responses from Australian STEM teachers. The presence of a range of skills that are specific to STEM disciplines is therefore supported. However, with the exception of Siekmann and Korbel (2016), the reports examined and the teachers surveyed view STEM skills as covering a much broader array of skills than those that are unique to STEM.

Higher Order Thinking

Higher order thinking skills were spread across the skills and abilities designations within the work of Carnevale et al. (2011) and featured within the work of Aring (2012). This accounts for the presence of several higher order thinking skills being present within the list used in the DAE (2014) survey. This is in strong contrast with Siekmann and Korbel (2016) who, whilst acknowledging the importance of these skills, chose to exclude them from their focus arguing that they are not unique to STEM. While higher order thinking skills are not, however, unique to STEM, skills such as critical thinking, creativity and problem solving are explicitly mentioned in reports such as the National STEM School Education Strategy (Education Council, 2015) and state and territory strategies as being developed within STEM education. They are also specifically mentioned in peer-reviewed literature that articulate STEM skills (Achat-Mendes et al., 2019; Aris & Orcos, 2019; Cheng, 2019; Eppes et al., 2012)

Australian Year 7-10 STEM teachers are certainly in line with the general attitude that higher order thinking skills are developed within STEM with it accounting for 34% of all responses – this was made up of 15% who referred to general higher order thinking skills, the 11% who listed problem solving and the 8% who focused on creativity – making it the most popular response. The strong focus placed on higher order thinking by teachers is perhaps enhanced by the fact that the focus on these skills in the Australian school system has been increasing for decades (Forster, 2004). This has culminated with the inclusion of critical and creative thinking as one of the seven general capabilities within the Australian Curriculum (ACARA, 2013c).

Thus, with the exception of the deliberate exclusion of such skills by Siekmann and Korbel (2016) in favour of the ‘technical skills’ specific to STEM, there is strong agreement between the literature, both presented in this chapter and in earlier chapters, and the teachers who responded to the survey about the place of higher order thinking within STEM skills.

Interpersonal skills

The focus upon interpersonal skills within the literature examined in Part 1a of this chapter was varied, with neither Carnevale et al. (2011) nor Siekmann and Korbel (2016) mentioning these skills at all. However, interpersonal skills were one of the four typologies that were found to underpin many of employability skills within the work of Aring (2012). Furthermore, interpersonal skills were included within the survey by DAE (2014) and were important or very important to all industry sectors surveyed (Prinsley & Baranyai, 2015). Communication was identified as the most important skill that was omitted from the list used in their survey (DAE, 2014). General and disciplinary-specific forms of communication have been identified by various researchers as being important within STEM (Achat-Mendes et al., 2019; Cheng, 2019; Eppes et al., 2012). Thus, STEM employers certainly appear to place a strong value on interpersonal skills, despite them not being specific to STEM. This view was supported by the respondents to the survey as presented in Part 1b, with collaboration and communication featuring strongly. These skills were also implied within several responses that were classified as pedagogical approaches in that many of them involved group-based project work.

Intrapersonal skills

As for interpersonal skills, intrapersonal did not feature in the work of Carnevale et al. (2011) nor Siekmann and Korbel (2016) yet, as for interpersonal skills, they were a typology of Aring (2012) and argued to underlie the majority of employability skills listed in that report. A few intrapersonal skills were in the DAE (2014) list of skills and many such skills were akin to the attributes identified by teachers within the survey discussed in Part 1b. Therefore, there is some argument for the inclusion of such skills within a framework of STEM skills, in particular, motivation and time management which have been discussed within STEM-based literature (Achat-Mendes et al., 2019; Aris & Orcos, 2019). While they were not the focus of some of the literature studied here, these intrapersonal skills are vital for success in any profession and thus, while not explicitly stated by some authors, perhaps are implicit.

Overall. The skills identified from the literature in Part 1a are, by and large, in agreement with the views of Australian Year 7-10 STEM teachers in Part 1b. Arguably the most well supported domain identified from the literature was disciplinary skills and this category was the second most populated category from the survey of teachers. The types of higher order thinking, interpersonal and intrapersonal skills identified from the literature were in agreement with those of the survey. However, perhaps most interestingly, the literature referred to in Part 1a and the teacher responses in Part 1b placed very little focus on literacy and thus they are agreement with each other. However, they are not in agreement with the literature-based arguments presented in Chapters 2 and 3 which stress the importance of STEM literacy for all. Nor are they in alignment with the use of a test such as PISA, which focuses on disciplinary literacy skills, as one of the most frequently used metrics for STEM skills. Thus, it can be concluded that the views presented in the literature are essentially shared by Year 7-10 Australian STEM teachers. However, the diversity of skills presented in the literature as well as listed by survey respondents highlights the lack of clarity around the term STEM skills. It can be used to refer to a huge array of skills and often refers to skills that are not STEM-specific. Thus, the proposition by Siekmann and Korbel (2016) that the phrase STEM skills ought not be used at all has some merit as the subset of skills meant by one person's use of the phrase STEM skills will be different from that of another.

Summary of Chapter 5

In Part 1a of this chapter, a range of key reports that articulate STEM skills were studied to create a framework of skills suitable for development in high schools. The work of Carnevale et al. (2011) and Aring (2012) was examined as their reports were the primary sources for the survey conducted by DAE (2014), as discussed in the report by Prinsley and Baranyai (2015). While Siekmann and Korbel (2016) assessed similar materials with a focus on STEM skills for the vocational sector, they decided to focus only on what they call technical skills (synonymous with the domain of disciplinary skills as proposed at the end of Part 1a). In proposing a range of STEM skills suitable for development within high schools, the decision was made to retain each of the domains identified from all of the reports examined in Part 1a as there was support from the conventional literature for these skills within STEM and so the framework paints a more holistic picture of what may typically be meant by the phrase STEM skills.

The results of the survey of Australian Year 7-10 STEM teachers presented in Part 1b of this chapter revealed a number of important findings. In Section 1 it was established that while teachers from across the country participated and that their personal demographics were representative of Australian teachers, the proportion of teachers from various states and territories and sectors was not representative of the actual Australian distribution. This is largely due to the previously described sampling issues. Section 2 showed that the majority of participants had heard of STEM skills before, many of them through multiple sources, demonstrating the prevalence of a focus on STEM in Australian education today. Section 3 presented what responding teachers associated with the phrase STEM skills so that a comparison between perspectives on STEM skills in the literature could be compared with those of Australian teachers in Part 1c of this chapter. On the whole, it was found that both the literature and Australian Year 7-10 STEM teachers associate a very wide variety of skills with the phrase STEM skills with a fair amount of overlap in the skills identified from the two groups.

In the following chapter, the STEM skill domains which arose from the literature, as shown in Figure 7, will be compared with the skills that feature within the general capabilities, cross-curriculum priorities and STEM learning areas of the Australian Curriculum.

Chapter 6 – Results and Discussion for Research Question 2 – To what extent does the Australian Curriculum support the development of STEM skills?

2a. What skills are made explicit in the general capabilities, cross-curriculum priorities and STEM learning areas of the Australian Curriculum?

2b. To what extent do Australian Year 7-10 STEM teachers feel the Australian Curriculum supports them in developing STEM skills in their students?

Introduction

For the purposes of this Chapter, any comparison to STEM skills pertains to skills that fall into any of the five domains that emerged at the end of Chapter 5 Part 1: literacy; disciplinary; higher order thinking; interpersonal; and intrapersonal: that is, those domains that were identified from the literature.

Part 2a of this chapter commences with an analysis of the extent to which the Australian Curriculum supports the development of STEM skills. This involved an examination of the general capabilities, cross-curriculum priorities and the STEM learning areas: Mathematics, Science and the Technologies. The general capabilities are presented one at a time and the skills identified within any description pertaining to each capability are stated. This is followed by a discussion of the extent to which each general capability may be developed within each of the STEM learning areas. This is done on the basis of the proportions of content descriptions and elaborations that have been tagged by ACARA as suitable contexts for a focus on that capability. A similar format is then used to present the three cross-curriculum priorities. The STEM learning areas are then presented one at a time. Each component of the curriculum (Rationale, Aims and so on) is examined and skills noted. The proportions of content descriptions and elaborations tagged with each general capability and cross-curriculum priority are depicted graphically. Part 2a concludes with a summation of how each of the three components of the curriculum support the development of STEM skills.

The focus then shifts to the perspectives of Year 7-10 Australian STEM teachers to address Research Question 2b. The respondents for this Research Question are a subset of those who completed the survey discussed in Chapter 5 Part 1b. Only those teachers who were teaching an Australian Curriculum course at the time of completing the survey were asked to complete the sections of the survey analysed within this Chapter. The demographics of this sub-group are presented so that the sample of teachers responding to this question could be compared with the sample of teachers who completed the whole survey, as well as the Australian Year 7-10 STEM teacher population. This is followed by a presentation of teacher familiarity with each of the components of the curriculum analysed in Part 1 of this chapter. It concludes with a discussion of comments from survey respondents regarding how supportive they feel the curriculum is for the development of STEM skills in their students.

Please note that results and discussion are presented together throughout this chapter.

Research Question 2a – What skills are made explicit in the general capabilities, cross-curriculum priorities and STEM learning areas of the Australian Curriculum?

General capabilities

An analysis of the description of each of the general capabilities and how they may be addressed within the curriculum was carried out to see the range of skills identified within each capability. The proportion of content descriptions and elaborations tagged with each general capability was determined to ascertain the direct support given to teachers regarding appropriate contexts through which to explore the general capabilities.

General capabilities – Literacy. The description of the literacy capability commences with "In the Australian Curriculum, students become literate as they develop the knowledge, skills and dispositions to interpret and use language confidently for learning and communicating in and out of school and for participating effectively in society" (ACARA, 2013f, para. 1). This indicates that literacy is to be considered as more than just reading and writing, it is an important life skill. A range of standard literacy skills are outlined, in particular the ability to "access, understand, analyse and evaluate information, make meaning, express thoughts and emotions, present ideas and opinions, interact with others and participate in activities at school and in their lives beyond school" (ACARA, 2013f, para 2). In addition to this, analytical skills, the ability to form an argument as well as to communicate and collaborate are noted. Furthermore, it is stated that confident, motivated learners will be able to develop literacy skills more effectively. Finally, a range of other behaviours and dispositions are identified as being developed within the literacy capability. These include being able to work independently as well as with others, being open to ideas and opinions, being prepared to return to tasks to improve them and the questioning assumptions. Thus, the description of literacy taps into each of the domains of STEM skills outlined at the end of Part 1a of Chapter 5, except for disciplinary skills.

In terms of the relative positioning of the STEM disciplines alongside other learning areas, Technologies had the fifth highest proportion of content descriptions referring to literacy while Mathematics and Science ranked seventh and eighth respectively. Within the Technologies, mention is made of communication, the necessity of interpreting and constructing technological and engineering texts and using critical thinking to evaluate ideas. In Mathematics, the necessity to engage with mathematical vocabulary and thus the development of mathematical literacy is the key focus. Problem solving and the ability to communicate solutions are also mentioned. In Science a broad scientific literacy that students can apply in the world is noted, as is the ability to communicate evidence-based arguments, which arguably are underpinned by critical thinking (ACARA, 2013f). Figure 18 shows the percentage of content descriptions and elaborations tagged with the Literacy icon across the STEM learning areas.

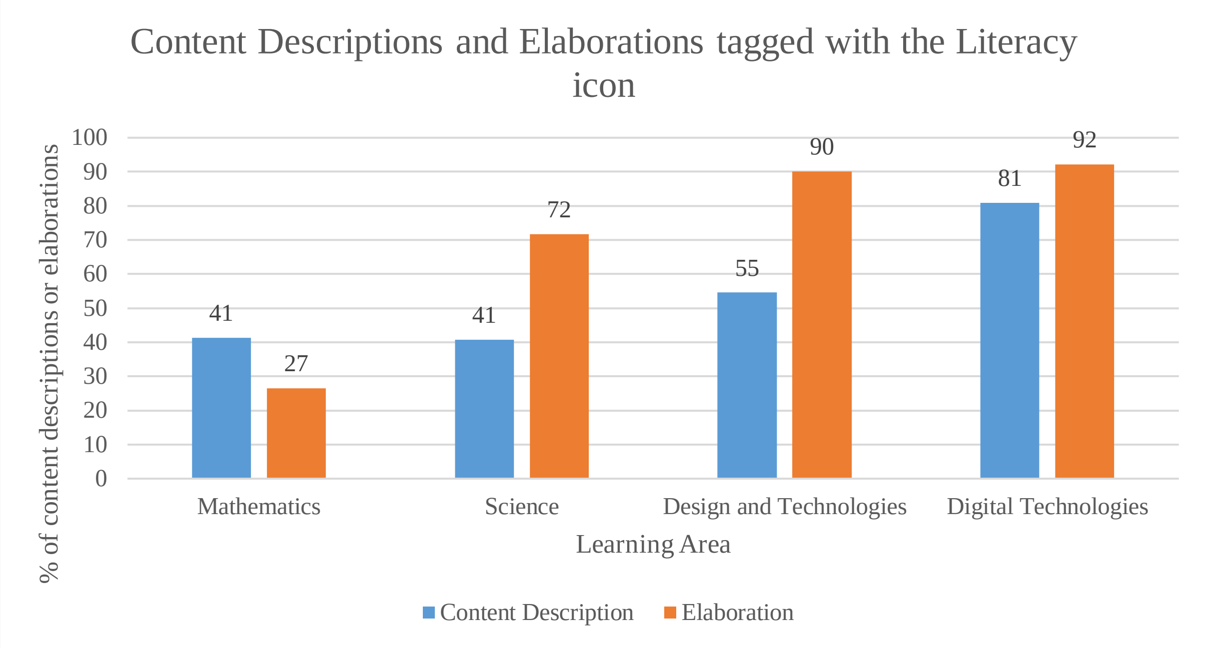

Figure 18 – Percentage of content descriptions and elaborations tagged with the literacy icon within STEM learning areas

The proportion of tags pertaining to each STEM discipline demonstrates that literacy, both disciplinary literacy as well as general literacy skills, has ample opportunity for development within the STEM learning areas.

General capabilities – Numeracy. The preface to numeracy highlights the importance of developing mathematical literacy through this general capability: “it involves students recognising and understanding the role of mathematics in the world and having the dispositions and capacities to use mathematical knowledge and skills purposefully” (ACARA, 2013g, para. 1). The use of mathematical skills to solve problems within authentic contexts is a recurring theme throughout the description of numeracy, with the obvious development of a range of mathematical skills (ACARA, 2013g). The learning continuum indicates that, while the focus is generally on the development of mathematical skills, problem solving, communicating findings and critical thinking skills, such as the ability to analyse and evaluate data, were also highlighted (ACARA, 2013h).

Unsurprisingly Mathematics is the learning area with the most frequent tagging of numeracy in its content descriptions, followed by Digital Technologies, with Design and Technologies ranking third and Science fourth. Within Mathematics, there was a focus on how the development of numeracy and mathematical understanding more broadly may be applied to other learning areas and relevant real-world contexts which is, at least in part, getting at the importance and nature of mathematical literacy. There was also mention of applying understanding, specifically of measurement and geometry, to design as well as the ability to interpret data and to make informed judgements. Many skills are referred to within the description of how numeracy may be developed within the Technologies. First, there is a description of the numeracy skills required as well as a range of mathematical skills that can be developed within the Technologies. This then broadens to include interpretation of data, the ability to draw conclusions, generate ideas, manage ongoing projects, computational thinking and the ability to design and create the best fit solutions to a given problem. The overwhelming focus within the description of the place of numeracy within Science is its usefulness in the collection and interpretation of data, in particular the graphical and/or statistical analysis of quantitative data and the use of evidence to support a hypothesis (ACARA, 2013g). The focus within this capability pertains to disciplinary skills, with some connections to mathematical literacy and higher order thinking through problem solving.

Figure 19 shows the distribution of content descriptions and elaborations tagged with numeracy across the STEM disciplines.

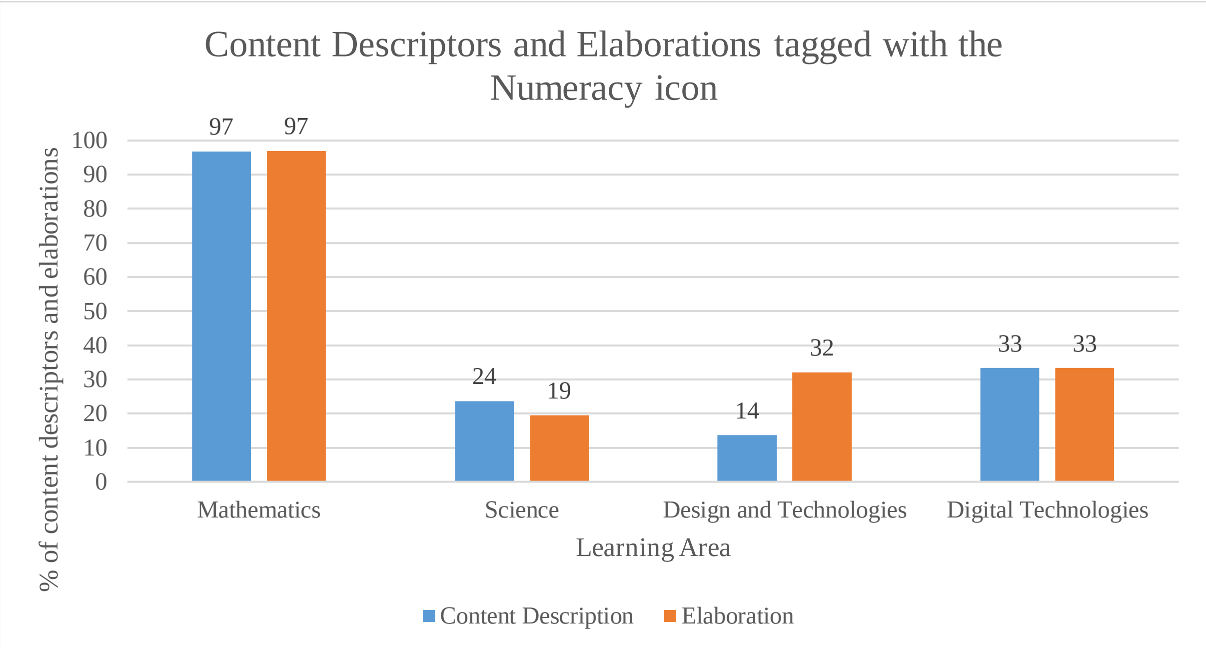

Figure 19 – Percentage of content descriptions and elaborations tagged with the numeracy icon within STEM learning areas

Practically every descriptor and elaboration in Mathematics is tagged with numeracy, which is perhaps to be expected given how central numeracy is to mathematics. Whilst Technologies and Science ranked third and fourth respectively, there is not an abundance of content descriptions being tagged, in Design and Technologies in particular. But even Science, many units of which involve mathematics, only has 24% of its descriptions tagged with this capability.

General capabilities – Information and Communication Technology (ICT) Capability. This capability, whilst clearly central within Digital Technologies, is of ever-increasing importance within today's world. This capability is designed to help

> students develop Information and Communication Technology (ICT) capability as they learn to use ICT effectively and appropriately to access, create and communicate information and ideas, solve problems and work collaboratively in all learning areas at school and in their lives beyond school (ACARA, 2012c, para. 1).

This capability is very wide-ranging in scope, referring to a large variety of skills. It covers not just the ability to access, create and present information (along with other attributes encompassed within technological literacy), but also problem solving, decision making, active learning, empirical reasoning, the conduction of research, analysis of data, designing solutions to problems, and the ability to work independently as well as collaboratively (ACARA, 2012c).

There are five interrelated elements in this capability, each of which focuses upon a different skill set. In 'applying social and ethical protocols and practices when using ICT' the focus is upon the students' appropriate use of technology, which overlaps with technological literacy and digital citizenship. It requires the ability to assess the risks and impacts of decisions. Research and organisational skills, as well as analysis and critique of data and information, are covered within 'investigating with ICT'. Creativity is the focus within 'creating with ICT', particularly with respect to using ICT to solve complex problems and to communicate in a range of different ways. Communication and collaboration are key within 'communicating with ICT'. Finally, the technical skills needed to develop and select appropriate hardware and software to manage and maintain digital data are developed within 'managing and operating ICT' (ACARA, 2012c; ACARA, 2013d). This capability therefore involves at least one skill from each of the five STEM skill domains.

The Technologies is the learning area with the greatest number of content descriptions tagged with the ICT capability, with Mathematics placing fourth and Science sixth. Within the description of the Technologies, a wide variety of these skills are reiterated. Students are to use computational thinking and algorithmic logic to investigate and create digital solutions, organise and analyse data and other information, evaluate design ideas, collaborate and communicate. In Mathematics, the focus is more on using ICT to "investigate, create and communicate mathematical ideas and concepts" (ACARA, 2012c) as well as to analyse, interpret and present data. Similarly to the Mathematics description, ICT within Science is described essentially as a tool for supporting students to investigate phenomena, enhance understanding of phenomena that are not easily observable, to analyse and represent data and communicate their understanding (ACARA, 2012c).

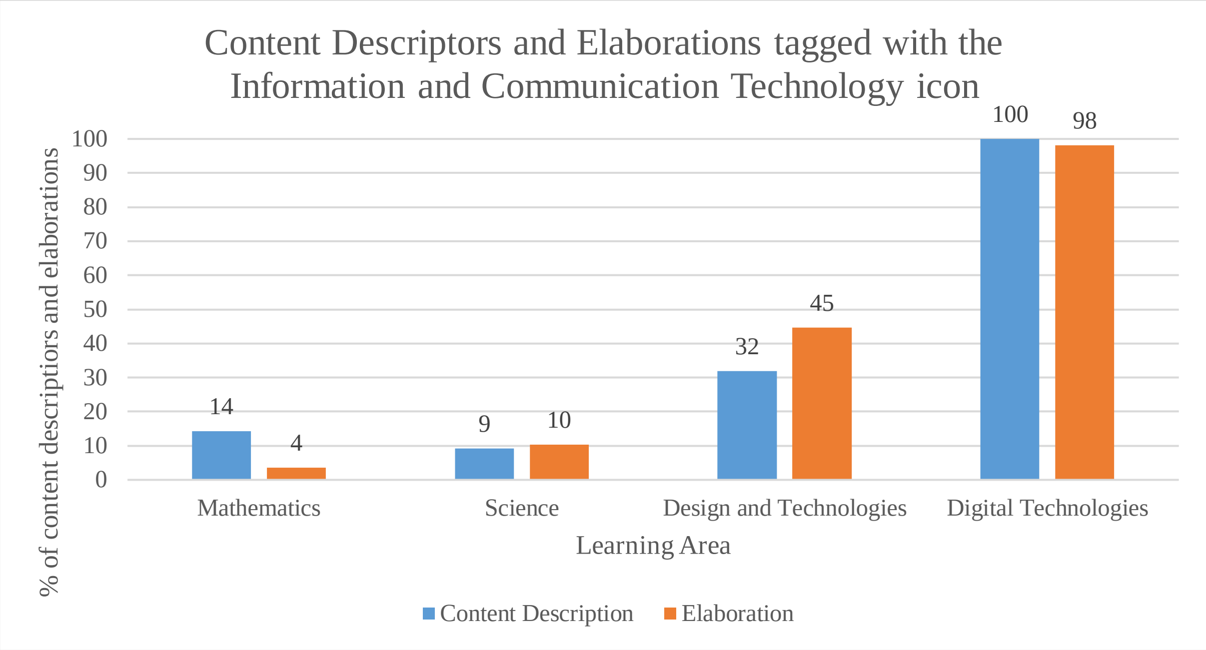

Figure 20 – Percentage of content descriptions and elaborations tagged with the information and communication technology capability icon within STEM learning areas

While Digital Technologies has the largest proportion by far of content descriptors and elaborations tagged with this capability, Design and Technologies also has quite a high proportion. Mathematics and Science have far fewer content descriptions and elaborations tagged, despite the overview of the capability indicating the importance of the capability to these disciplines.

General capabilities – Critical and creative thinking. This general capability highlights the importance of a range of thinking skills and goes so far as to argue that

> The imparting of knowledge (content) and the development of thinking skills are accepted today as primary purposes of education. The explicit teaching and embedding of critical and creative thinking throughout the learning areas encourages students to engage in higher order thinking (ACARA, 2012a, para. 20).

This capability is focused not just upon critical and creative thinking, but higher order thinking skills more generally. Critical thinking is described as being “at the core of most intellectual activity that involves students learning to recognise or develop an argument, use evidence in support of that argument, draw reasoned conclusions, and use information to solve problems.” Creative thinking on the other hand “involves students learning to generate and apply new ideas in specific contexts, seeing existing situations in a new way, identifying alternative explanations and seeing or making new links that generate a positive outcome” (ACARA, 2012a, p. para. 6).

Within the description of these two types of thinking and how they are to be developed in this capability, an extensive range of skills as well as dispositions are identified. Students are to develop the skills needed to: generate as well as evaluate options; to consider a range of alternatives in solving problems; to articulate and evaluate reason and logic; to be resourceful, imaginative and innovative; to be able to transfer knowledge to unfamiliar scenarios; and develop an evidence-based argument, to list just a few. To do this, students need to develop a range of dispositions that are also articulated as either being pre-requisites for critical and creative thinking, or as attributes that engaging in critical and creative thinking would help to develop. These include: confidence, persistence, motivation for their own learning, being adaptable as well as open- and fair-minded, to have an inquisitive and questioning nature as well as a desire to seek solutions (ACARA, 2012a).

It is interesting to note that the Humanities is the learning area with the highest proportion of content descriptions tagged with this capability with the Technologies placing third (behind the Arts), Mathematics seventh and Science eighth (of eight). This is a somewhat surprising finding given the focus placed in the STEM literature on critical thinking (Achat-Mendes et al., 2019; Cheng, 2019, OCS, 2014a). Whilst this capability is clearly significant within all learning areas, it is often described as being particularly well-developed within the STEM disciplines and was considered by all sectors of the workforce surveyed by DAE (2014) to be more well developed in their STEM-trained employees.

In each of the STEM discipline area descriptions, note is made of the fact that students will develop critical and creative thinking as they generate ideas and knowledge, critically evaluate their ideas and use them to identify solutions to problems. Within the Technologies a range of other more specific skills are also listed, such as: abstraction, reflection, systems design, and computational, visual and spatial thinking. In Mathematics, reasoning and justification regarding the choice of strategies to use in solving problems is highlighted, as is the ability to ask relevant questions and be open to alternative approaches. The description of this general capability within Science highlights a range of practical science skills such as the ability to pose questions, make predictions, evaluate evidence and use this to make evidence-based decisions. Dispositions such as flexibility and open-mindedness are also noted. Therefore, the vast majority of skills mentioned fall into higher order thinking. The mention of the dispositions required also allude to a range of intrapersonal skills.

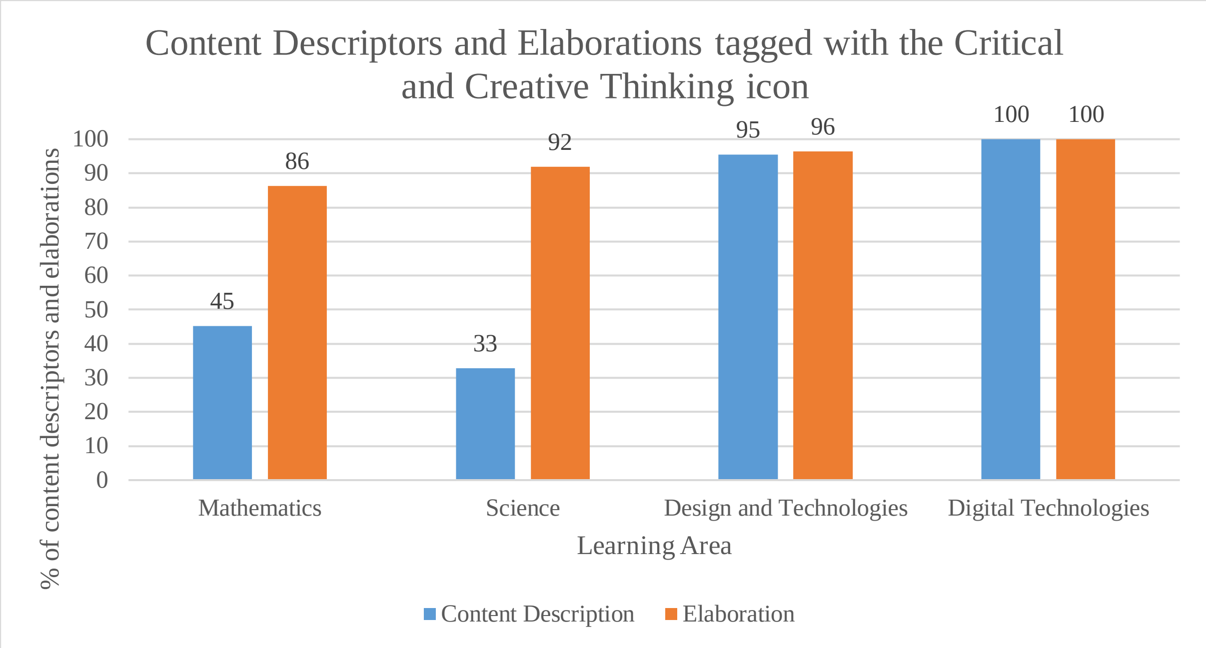

Figure 21 – Percentage of content descriptions and elaborations tagged with the critical and creative thinking icon within STEM learning areas

While a very high proportion of elaborations for all STEM disciplines was noted, the two Technologies subjects have a much higher proportion of content descriptions that are also tagged. This is to be expected given Mathematics and Science placed second last and last respectively in terms of proportion of content descriptions tagged. Having said this, they had 45% and 33% of descriptions tagged respectively, which indicates the central importance of this capability to all learning areas.

General capabilities – Personal and Social Capability. This capability is of strong importance for the development of interpersonal and intrapersonal skills and directly addresses key statements of the Melbourne Declaration on Educational Goals for Young Australians (ACARA, 2012e). It is explained that, while the capability is comprised of the terms personal and social, the literature from which this capability was defined uses the words personal/emotional and social/relational interchangeably and that it is akin to "social and emotional learning" (ACARA, 2012e, para. 4). The description of this capability indicates that it is developed as students "learn to understand themselves and others, and manage their relationships, lives, work and learning more effectively" (ACARA, 2012e, para. 1). In order to achieve this, students need to develop the capacity to regulate their own emotions, have empathy for others, collaborate, deal with setbacks and lead where necessary.

The four key ideas for this capability are: self-awareness; self-management; social awareness; and social management. The description of self-awareness includes an awareness of themselves in general as well the factors that affect their learning. The self-motivation element describes the ability to work independently, show initiative, delay gratification, identify effective strategies to help them achieve their own goals and to persevere during setbacks. The remaining two elements have a social component and thus emphasise interpersonal skills more strongly. The social awareness element seeks to help students to identify their own views, develop an appreciation for diverse perspectives, contribute to society, and to understand the nature of different social relationships. The social management element has the greatest number of sub-elements and highlights the importance of clear communication, collaboration, the ability to make decisions, develop a range of strategies for negotiating and resolving conflict and leadership skills (ACARA, 2012e; ACARA, 2013i).

The Technologies is the fourth most highly ranked subject with regard to this capability, possibly due to its focus on project management and the provision of opportunities for collaboration as well as to direct students' own learning. The description also makes specific mention of employability skills developed through working in teams in this learning area. The development of this capability is described within the context of engaging in design thinking to create innovative solutions to problems whilst considering the impacts of design decisions on society. Within Science (seventh) this capability is described predominantly within a scientific literacy context, particularly in terms of how science affects and can be applied to students' personal lives, as well as the community more broadly speaking. Clear mention is also made of the need to develop communication skills, initiative, the ability to work independently and collaboratively and that the development of these personal and social skills will enhance students' problem solving ability. Finally, in the rather short description of the place of this capability within Mathematics (eighth), it is stated that by applying mathematical skills within personal and social contexts students may develop this capability, with some allusions to mathematical literacy. It is indicated that Mathematics can enhance the development of personal and social skills because this learning area provides opportunities for showing initiative, communicating and working independently as well as collaboratively (ACARA, 2012e). Interestingly, the potential for Mathematics to help students to develop self-motivation, resilience and the willingness to take risks was not mentioned, despite Mathematics being a subject with which many students struggle and thus need to utilise these character traits.

While this capability has strongest links to interpersonal and intrapersonal skills, various disciplinary literacies were alluded to and contexts requiring higher order thinking skills were noted as being a good place in which to cultivate these interpersonal and intrapersonal skills.

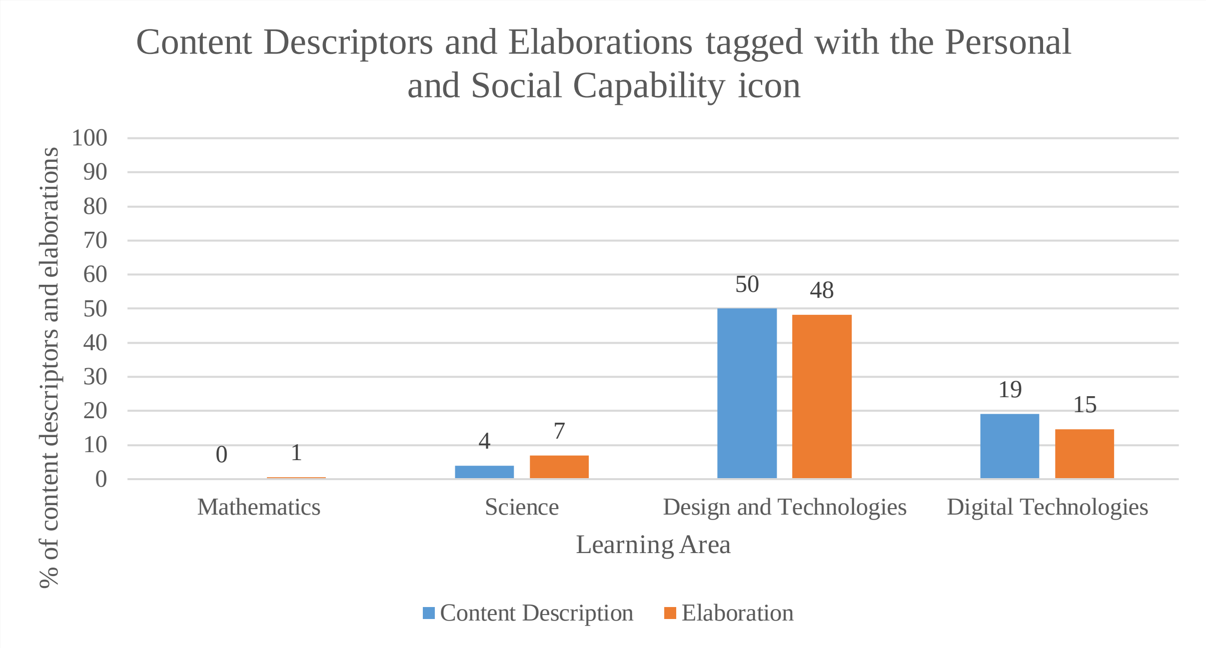

Figure 22 – Percentage of content descriptions and elaborations tagged with the personal and social capability icon within STEM learning areas

While half of the Design and Technologies content descriptions and elaborations are tagged with the Personal and Social Capability icon, Science has very few explicit links to this capability while Mathematics has no content descriptions and only one elaboration across all four year-levels tagged with this capability. As content descriptions contribute most strongly to the construction of teaching programs (elaborations are examples only while content descriptions are compulsory), the chances of this capability being meaningfully enacted by mathematics and science teachers in the classrooms seems low. While the overview of this capability makes a strong argument for its inclusion within all learning areas, little explicit mention is made and therefore very little to no support is provided to teachers regarding how to cultivate this capability within their learning area.

General capabilities – Ethical Understanding. Specific mention of the Melbourne Declaration is again made within this general capability and there are allusions to literacies in terms of the effects of disciplines, technology in particular, on society. This capability is focused upon developing an ethical outlook on life and thus refers to honesty, resilience, empathy and respect for others. The need to demonstrate consistency and reasoning in making decisions when working independently or with others is also noted. There are three interrelated elements which highlight the importance of a range of critical thinking skills, including the ability to critique, analyse, evaluate and use reasoning skills. Collaboration and communication are also of clear importance for this capability (ACARA, 2013a; ACARA, 2013b).

The Technologies is placed second behind Humanities and Social Sciences in terms of the frequency of Ethical Understanding tags in its content descriptions. This is of little surprise as the

Technologies learning area frequently asserts the need to consider factors such as user needs, sustainability and the impact of design on society – all of which involve ethical considerations. Science places sixth in terms of frequency of this capability despite scientific advancements and how society chooses to use them being strongly subject to ethical review (Allchin, 2011). Therefore, students should develop an awareness of relevant ethical considerations and procedures used within Science during their high school Science education. The description of ethical understanding within Science is quite brief and indicates that students can develop this capability through ethical considerations in investigations they conduct as well as how science is used and applied within society in a manner that has some connection to their broader scientific literacy. The articulation of the place of this capability within Mathematics is only one sentence, albeit it a long one, which has some connection to mathematical literacy in terms of how data, claims and sources may be interrogated (ACARA, 2013a). This would appear to not be very helpful in terms of giving teachers ideas about how they may meaningfully address this capability. This capability is deeply important in a wide range of contexts and one all young people should develop. However, the description of how this capability applies to the learning areas is the weakest so far in terms of the provision of suggestions to help teachers to genuinely develop ethical understanding within their students. Some connections are made to the literacy, higher order thinking, and interpersonal domains are made, but they are weak.

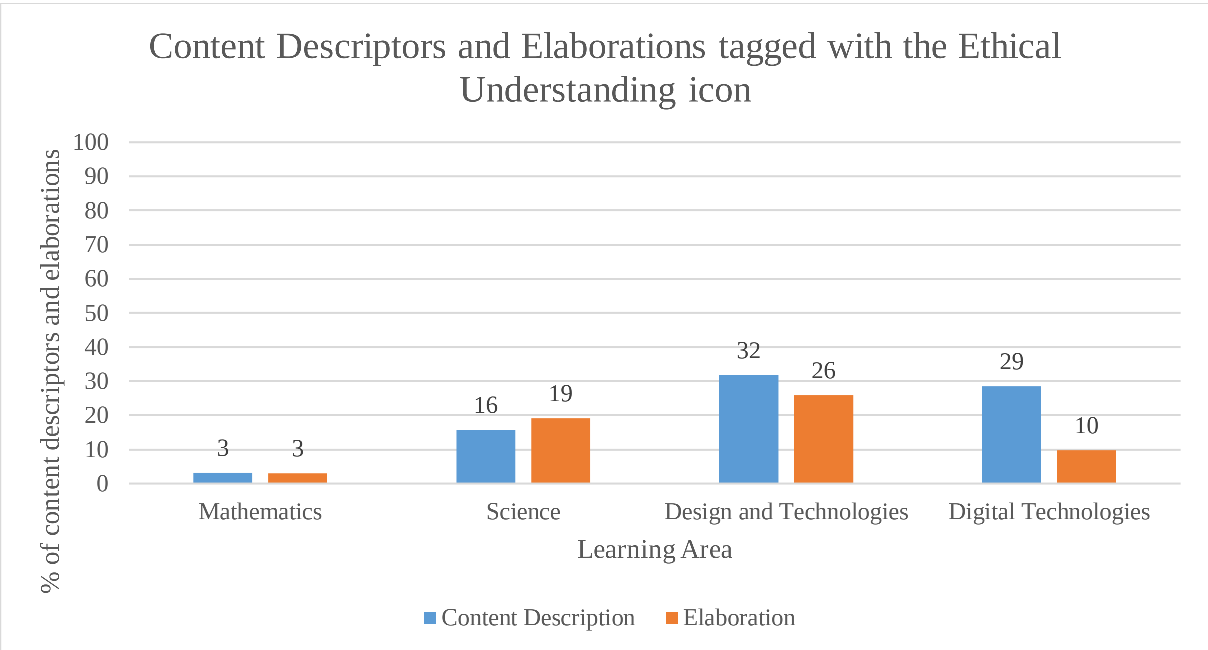

Figure 23 – Percentage of content descriptions and elaborations tagged with the ethical understanding icon within STEM learning areas

Compared with other capabilities, ethical understanding is not well represented in STEM learning areas, with a low proportion even for the Technologies considering it placed second in terms of the proportion of content descriptions tagged. Perhaps this is understandable though as, while some topics across all learning areas would lend themselves to a detailed analysis of the ethical implications, others do not.

General capabilities – Intercultural Understanding. The final general capability focuses upon helping students to develop an appreciation of the beliefs, cultures and languages of others, which is of great importance for life in multicultural societies such as Australia. The description of this capability highlights it as one in which students can increase their communication and critical thinking skills by reflecting on the attitudes and beliefs of themselves and others. Dispositions such as empathy, curiosity, care for others, respect and responsibility, open-mindedness, flexibility, adaptability, the development of multiple perspectives, and willingness to experience new things were all noted (ACARA, 2012d; ACARA, 2013e). It is stated that this general capability is

> more apparent in some learning areas than others, being most evident in those aspects of learning concerned with people and their societies, relationships and interactions, and with the cross-curriculum priorities for Aboriginal and Torres Strait Islander Histories and Cultures, Asia and Australia's Engagement with Asia, and Sustainability (ACARA, 2012d, p. para. 15).

Languages is the learning area with the highest proportion of intercultural understanding tags with Technologies, Science and Mathematics ranking sixth, seventh and eighth respectively. Given the description above of the types of learning areas with which this capability is most strongly aligned, it is not surprising that the STEM disciplines do not feature highly.

Within the Technologies description technological literacy is once again featured in terms of the impact of technology and its potential to transform people's lives. Consideration of how cultural identities and traditions influence projects is noted, as is the necessity of employing relevant social protocols in the face of challenges arising from cultural diversity. In Science the focus is on how students can learn to appreciate how intercultural understanding is played out within scientific disciplines more so than on how students may develop it themselves. For instance, the curriculum requires students to consider the contributions of diverse cultures to science, that some issues within science have cultural sensitivities associated with them, and that science as an international enterprise that involves people working in culturally diverse teams. While all of this is worth discussing with students and contributes to their understanding of the nature of science (Allchin, 2011), teachers are not provided with examples of how they may assist students to develop these skills. The Mathematics description highlights how mathematics uses universal symbols and that the processes of mathematics are not culture specific. It concludes with the statement that "students can apply mathematical thinking to identify and resolve issues related to living with diversity" but gives no examples of how teachers could meaningfully achieve this (ACARA, 2012d, p. para. 39). So, similarly to ethical understanding, how intercultural understanding is to be meaningfully developed within STEM subjects is not entirely clear. Likewise, while links are made to each of the STEM domains apart from disciplinary skills, these links are more tenuous than those made in the descriptions of other capabilities.

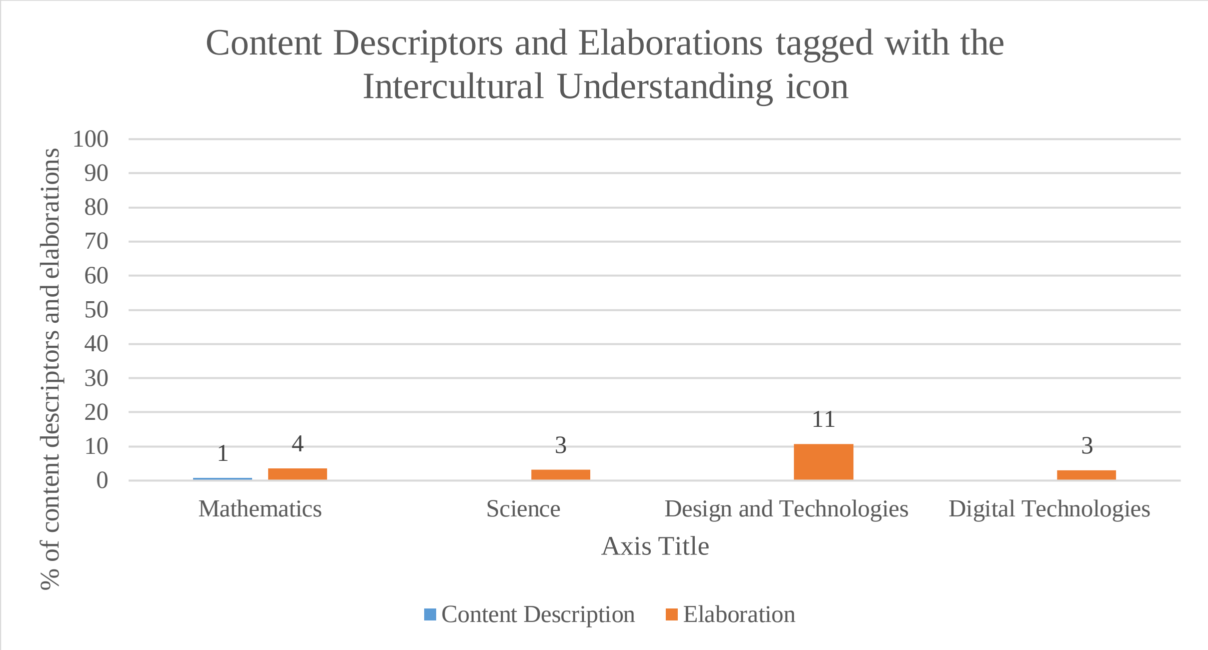

Figure 24 – Percentage of content descriptions and elaborations tagged with the intercultural understanding icon within STEM learning areas

Despite the existence of a description of the place of this capability within STEM subjects, Mathematics has one content description tagged with it and the other STEM disciplines have only a small proportion of elaborations. The guidance for teachers as to how to incorporate this capability within the STEM learning areas is practically non-existent.

General capabilities – Overall. The general capabilities, as indicated by the name, are general and thus designed to be developed within each of the learning areas. However, the learning area descriptions and relative proportion of content descriptions indicate that there is a greater propensity to address the capabilities in some learning areas than others. This is natural and to be expected as disciplines have their own unique characteristics and thus will be more likely to provide opportunities for the development of some skills over others. In the overview of each capability, the learning area specific advice was given in order based on the proportion of content descriptions tagged for each capability. While these were stated in the previous section, to provide an overview of how the different learning areas fare across the general capabilities as a whole, the position of each learning area for each capability is shown in Table 21.

Table 21 – Subjects ranked by relative proportion of content descriptions tagged with each general capability, each STEM learning area has been colour-coded for ease of location

Rank	Literacy	Numeracy	ICT	Critical and Creative Thinking	Personal and Social Capability	Ethical Understanding	Intercultural Understanding
1	English	Mathematics	Technologies	Humanities and Social Sciences	Health and Physical Education	Humanities and Social Sciences	Languages
2	Languages	Humanities and Social Sciences	The Arts	The Arts	The Arts	Technologies	The Arts
3	Humanities and Social Sciences	Technologies	Humanities and Social Sciences	Technologies	Languages	Health and Physical Education	Humanities and Social Sciences
4	The Arts	Science	Mathematics	Health and Physical Education	Technologies	The Arts	Health and Physical Education
5	Technologies	The Arts	English	English	Humanities and Social Sciences	Languages	English
6	Health and Physical Education	Health and Physical Education	Science	Languages	English	Science	Technologies
7	Mathematics	English	Health and Physical Education	Mathematics	Science	English	Science
8	Science	Languages	Languages	Science	Mathematics	Mathematics	Mathematics

As can be seen from Table 21, the STEM disciplines do not fare well in terms of content description tagging. It is understandable that some disciplines lend themselves to certain capabilities more so than others, and indeed some learning areas are more conducive to the extensive development of a wide range of capabilities. However, it is interesting to consider how poorly the STEM disciplines fare, Mathematics and Science in particular. These are, after all, *general* capabilities, which are deemed important for all students, regardless of the profession they ultimately choose to follow, and are meant to be developed by all teachers in all learning areas (ACARA, 2013c).

As the actual proportions of content descriptions tagged with each capability were not provided, merely a rank, the median is the most reliable way to compare relative positions of the learning areas as the data is ordinal. The median ranking for the learning areas, determined from the data in Table 21, is depicted in Figure 25.

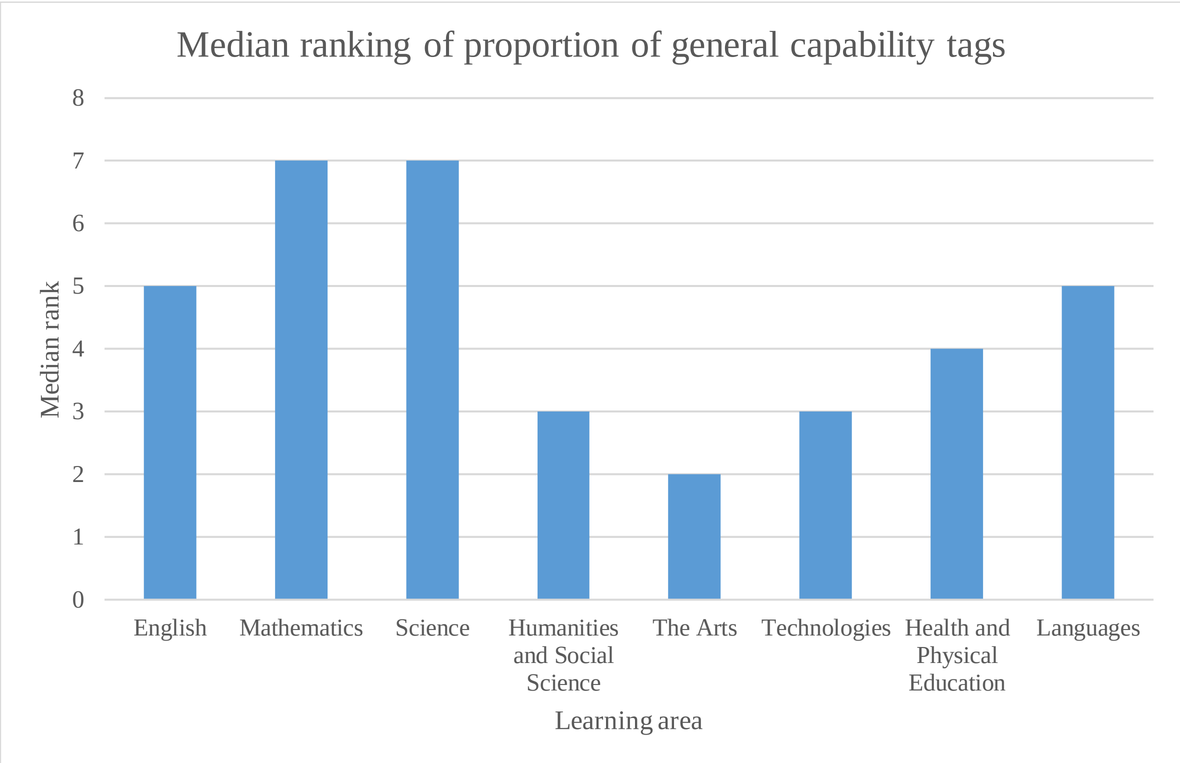

Figure 25 – Median ranking of the learning areas by proportion of general capability tags in the content descriptions. Note that as this is a ranking, lower numbers represent a higher.

Figure 25 clearly demonstrates just how poorly Mathematics and Science rate in terms of the extent to which support is given for the general capabilities to be developed within these learning areas. The Technologies do much better, placing equal second overall with Humanities and Social Sciences behind The Arts. This indicates that curriculum writers saw relatively limited opportunities for the development of the general capabilities in Mathematics and Science as opposed to the Arts and Humanities. The ranking for the critical and creative thinking capability is particularly revealing. It has often been argued that Science is a discipline that cultivates the development of critical thinking skills to a larger extent than others. Furthermore, Science relies heavily on creativity, despite the tendency of non-scientists to claim to the contrary (Lederman et al., 2002; McComas et al., 1998). However, Science placed last in the ranking. It ought to be noted that this ranking was based only on the content descriptions, not the elaborations. This was presumably because while the former are compulsory, the latter are not.

In terms of the representation of STEM skill domains as articulated at the end of Part 1a of Chapter 5, each domain is well-represented across the general capabilities as a whole, with the exception of disciplinary skills. This is to be expected as disciplinary skills are by nature specific to a discipline, not general. Disciplinary skills are more likely to be expressed within the learning areas themselves. Interpersonal and intrapersonal skills feature throughout the general capabilities. The literacy skills are described more as potential outcomes of developing a capability whereas the contexts within which these capabilities are to be developed typically involve the use of higher order thinking skills. Overall, the general capabilities provide ample support for the development of a range of skills, particularly within higher order thinking, interpersonal and intrapersonal domains.

Cross-curriculum priorities

In a similar manner as to what was done with the general capabilities, the descriptions of the cross-curriculum priorities were analysed to determine what skills were discussed for each. The proportion of content descriptions and elaborations tagged with each cross-curriculum priority was determined by way of seeing the direct support given to teachers regarding appropriate contexts in which to explore the three priorities.

Cross-curriculum priorities – Aboriginal and Torres Strait Islander Histories and Cultures. This cross-curriculum priority seeks to address two needs by way of closing the gap between Aboriginal and Torres Strait Islander students and their non-Indigenous peers. The first is to help students of Aboriginal and Torres Strait Islander descent to see themselves and their culture reflected within each of the learning areas. The second is to help all students to recognise and respect one of the world's oldest living cultures and to engage in ongoing reconciliation processes (ACARA, 2014a).

Within Mathematics, it is suggested that this priority could be considered when discussing different representations of number and patterns as well as time, place and measurement. Furthermore, the evaluation of statistical data related to Aboriginal and Torres Strait Islander people could be used to deepen students' understanding of Indigenous people and the opportunities and challenges they face. Within Science, it is indicated that students will have opportunities to learn that Aboriginal and Torres Strait Islander people have used their senses to make observations, have predicted and tested ideas and made generalisations regarding food, materials and the environment. In the Technologies it is suggested that students will explore the organising ideas with a focus on how Aboriginal and Torres Strait Islander Peoples sustain their environments (ACARA, 2014a). No explicit mention is made here of the skills students will use in learning about Aboriginal and Torres Strait Islander people and cultures.

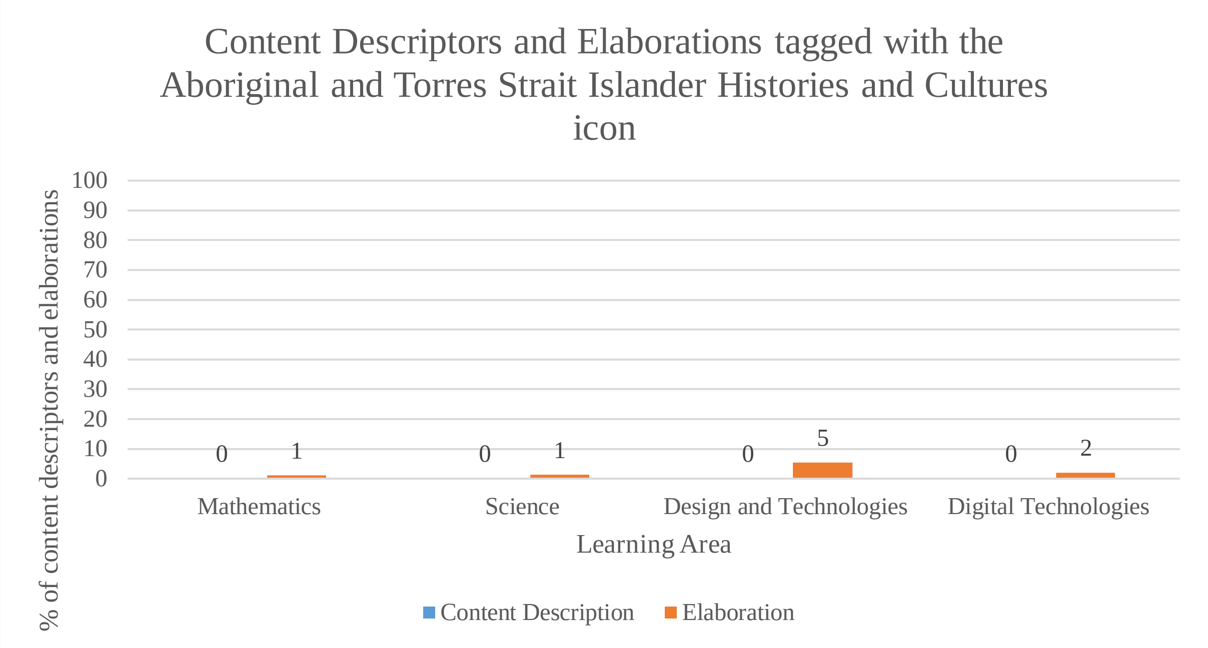

Figure 26 – Percentage of content descriptions and elaborations tagged with the Aboriginal and Torres Strait Islander Histories and Cultures icon within STEM learning areas

With Design and Technologies having the highest proportion of elaborations tagged (5%) and no content descriptions for any subject, there is little to no guidance provided to teachers with respect to how this cross-curriculum priority is to be addressed within STEM disciplines.

Perhaps to help address this, on 26th October 2018, an additional 95 elaborations were released across the F-10 Science curriculum to help to support teachers to more effectively embed this cross-curriculum priority within Science (ACARA, 2018c). This was warranted as only 1% of Science elaborations and no content descriptions were tagged with this cross-curriculum priority. However, the same is true of Mathematics, and the Technologies barely fared any better, as shown in Figure 26. Adding elaborations to Science is perhaps just a start, though no mention was made of any additional elaborations being added to any other learning area in the future. Figure 27 shows the distribution taking the additional Science elaborations into account.

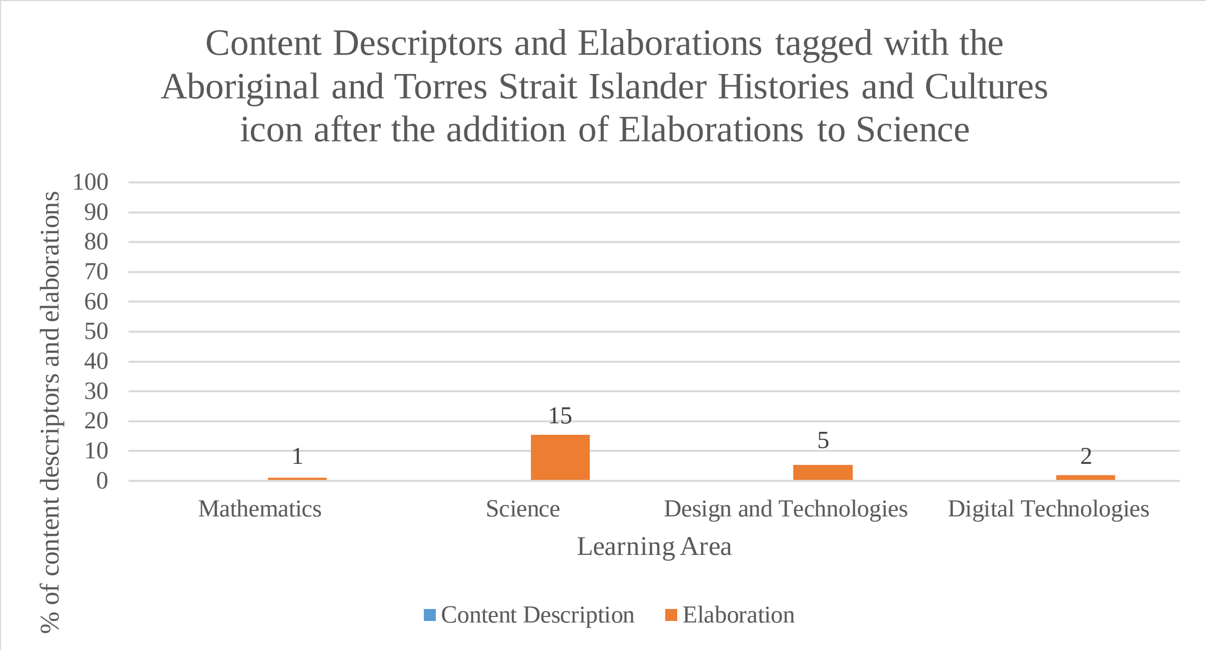

Figure 27 – Percentage of content descriptions and elaborations tagged with the Aboriginal and Torres Strait Islander Histories and Cultures icon within STEM learning areas after the addition of 95 additional elaborations to the Science curriculum in October 2018

These new elaborations boost the proportion of elaborations tagged with the Aboriginal and Torres Strait Islander Histories and Cultures cross-curriculum priority to a healthier 15%. However, the elaborations are not compulsory and they are only accessible by going to the website and expanding the content descriptions to see the elaborations. Thus, unless teachers review regularly, or saw the news article on the overview page of the Australian Curriculum website and then looked up the elaborations, they will be unaware that ACARA has added new ones. Therefore, the proportion of teachers aware of these new additions is questionable. It is also interesting that, while Science has had its elaborations boosted dramatically, not one content descriptor in the STEM disciplines is tagged with this priority, and the remaining STEM subjects have less than or equal to 5% of their elaborations tagged with it. Thus, the likelihood of this priority being well-developed within STEM disciplines is minimal. However, while this is problematic in terms of the perpetuation of a relative lack of understanding of Australia's indigenous culture, there are not many skills identified within this priority and thus it is arguably not a problem from the perspective of the development of STEM skills.

Cross-curriculum priorities – Asia and Australia's Engagement with Asia. This cross-curriculum priority is an area of focus due to the increasing influence Asia exerts globally, and within in the Asia Pacific region in particular. This priority encompasses social, cultural, political and economic aspects of Asia, and Australia's interaction with Asia (ACARA, 2014b).

Within Mathematics it is said that this priority can be explored through the development of an understanding of the contributions made by Asian mathematicians to many areas of mathematics, in addition to using data to analyse issues pertinent to the Asia region. In Science, the description focuses on encouraging students to recognise the contributions of people from the Asia region to developments in scientific research and development. Similarly, the Technologies suggest that students conduct an exploration of emerging technological advances in Asian countries and the interactions between peoples from different countries in the region to create sustainable products and services. Mention here is made of critical and creative thinking but this is the only explicit mention of a skill (ACARA, 2014b).

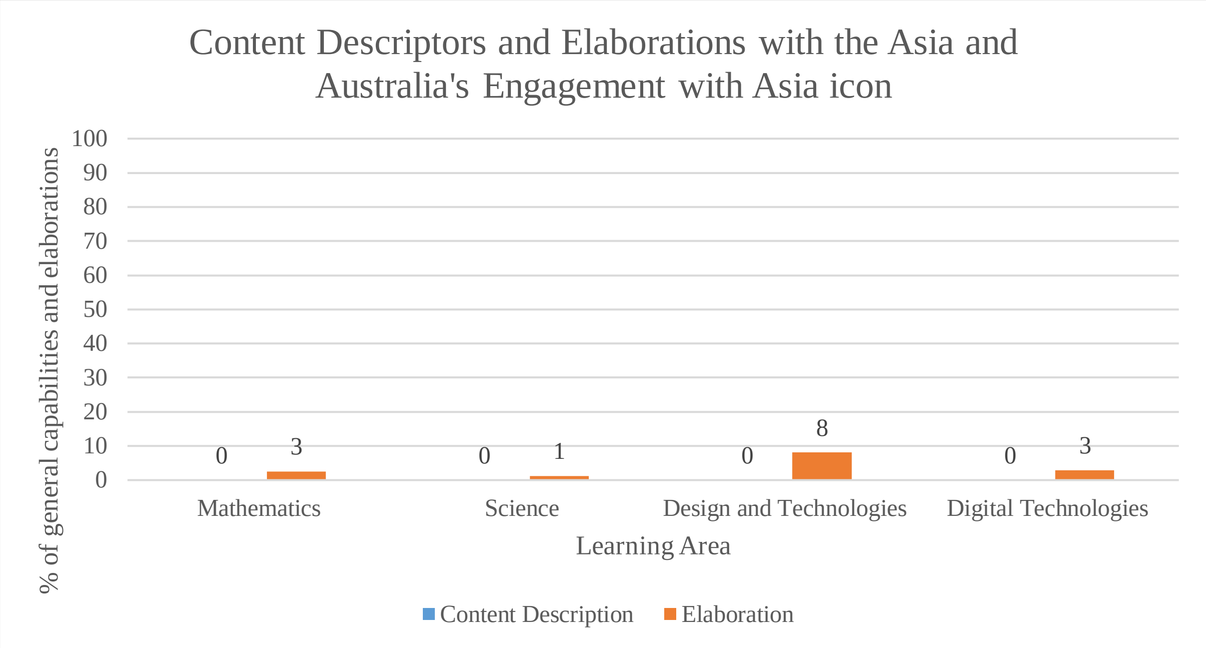

Figure 28 – Percentage of content descriptions and elaborations tagged with the Asia and Australia's Engagement with Asia icon within STEM learning areas

Like the first cross-curriculum priority, only a small number of elaborations for each STEM subject are tagged, indicating little connection between the priority and the STEM subjects. Again, this priority does not have a huge role to play within STEM, as evidenced by its lack of representation in those learning areas.

Cross-curriculum priorities – Sustainability. The opening of the description of this priority highlights a focus on sustainability as a way of connecting and relating relevant aspects of content across different learning areas to ensure the ongoing capacity of Earth to maintain life. The key concepts around which the organising ideas are structured are: systems; world views; and futures. The last of these "is aimed at building capacities for thinking and acting in ways that are necessary to create a more sustainable future" (ACARA, 2014d, p. para. 10). This has strong parallels with the aims of STEM (C. Smith & Watson, 2016).

Within Mathematics it is suggested that students can develop the problem-solving and reasoning skills required to propose sustainable solutions as well as to inform decision-making. In

Science the sustainability priority can be intertwined with learning about systems as part of the Science understandings strand. It is also indicated that this priority can help students to appreciate that Science often provides the basis for decision-making in society and that these decisions may impact the Earth system. The propensity for Science to be used to predict possible long-term effects of activities and to devise courses of action to minimise these effects is also noted. The Technologies has a strong focus on preferred futures and the description of this learning area within the Sustainability priority indicates that "When students identify and critique a problem, need or opportunity; generate ideas and concepts; and create solutions, they give prime consideration to sustainability by anticipating and balancing economic, environmental and social impacts" (ACARA, 2014d, p. para. 19). It goes on to indicate that students are to consider complex issues such as resource depletion and climate change when creating sustainable design solutions to problems. Additionally "understanding systems enables students to work with complexity, uncertainty and risk; make connections between disparate ideas and concepts; self-critique; and propose creative solutions that enhance sustainability" (ACARA, 2014d, p. para. 16). It is clear from the description that the Sustainability cross-curriculum priority is a strong focus within the Technologies. As Design and Technologies focuses upon creating solutions to problems with sustainability in mind through the creation of preferred futures, it has strong potential for the development of higher order thinking and disciplinary skills within a sustainability construct.

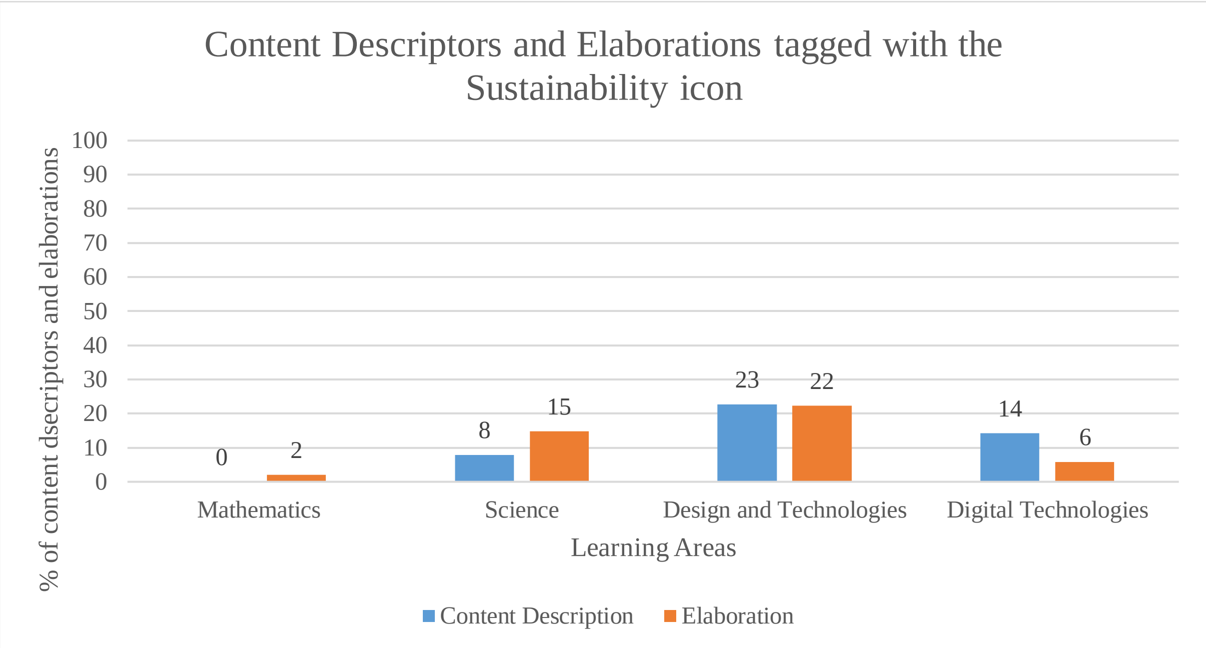

Figure 29 – Percentage of content descriptions and elaborations tagged with the Sustainability icon within STEM learning areas

While having greater representation than the other two cross-curriculum priorities, particularly for Design and Technologies, sustainability is not a huge focus within the content descriptions or elaborations for the STEM disciplines. Given its low representation with Science and the

Technologies, which have ample opportunity to address the priority, it is presumably covered to a low extent across the curriculum more broadly.

Cross-curriculum priorities – Overall. The cross-curriculum priorities do not have as many resources associated with them as the general capabilities. There are no learning continua and the information provided regarding the development of the priority in each subject is smaller than it was for the capabilities and is not provided in a separate document. Thus, there is less support provided to teachers seeking to authentically address the three priorities. The 'Aboriginal and Torres Strait Islander' and 'Australia and its engagement with Asia' priorities do not have many clear links in their descriptions to STEM skills, but the sustainability priority does have clearer potential to be used as a context within in which to develop students' higher order thinking as well as some disciplinary skills, particularly within the Technologies. It is worth noting that the accuracy of the term 'cross-curriculum' priorities given that they are not presented as being a priority in at least three of the eight learning areas.

Learning areas

The STEM learning areas, Mathematics, Science, and Technologies were each analysed in terms of the types of skills referenced throughout. The rationale, aims, key ideas, structure, sequence of content and sequence of achievement were included within the analysis. Any mention of a skill was coded via an inductive process. The general capability and cross-curriculum priority tagging of each content descriptor and elaboration was graphed to demonstrate the extent to which each are developed within each STEM area. This uses data from the previous section but presents it by learning area rather than by general capability or cross-curriculum priority.

Mathematics – Rationale. The Mathematics rationale focuses on the reasoning which underpins the Australian Curriculum for Mathematics. While there are of course references to mathematical and numeracy skills, the focus is upon how the development of these skills is important for students in their lives. The significance of mathematical reasoning is highlighted with examples given of how it will help students in problem solving, critical thinking, making informed decisions and being able to apply their understanding to different contexts. Note is made that the curriculum has been designed so that students can see the links between different branches of mathematics as well as how mathematics can be applied to different disciplines. Finally, it is highlighted that the Mathematics curriculum can help students to develop their self-motivation and confidence through the provision of opportunities for inquiry and active participation in their learning (ACARA, 2015l).

Mathematics – Aims. The Mathematics Aims are articulated within three dot-points yet, even within this very short description, a range of skills are mentioned. It is desired that students develop their confidence and creativity in using mathematics as well as their mathematical literacy in terms of how mathematics is relevant in their everyday lives. Additionally, students are to develop their understanding of mathematical concepts so that they can pose, as well as solve problems and apply reasoning (ACARA, 2015j).

Mathematics – Key ideas. Within Mathematics the key ideas are the four proficiency strands: understanding; fluency; problem-solving; and reasoning. A range of mathematical skills will be developed and applied across each of the strands. In the understanding strand, students need the ability to see connections between concepts and apply knowledge to new scenarios. Fluency, as the name suggests, is focused on the ability to perform mathematical calculations efficiently and effectively. Problem-solving and reasoning are both more broad and require a wider range of skills such as interpretation, modelling, communication, analysis and evaluation, deductive as well as inductive reasoning and critical thinking (ACARA, 2015k).

Mathematics – Structure. The Mathematics curriculum is organised by the interaction of the four proficiency strands and the three content strands: number and algebra; measurement and geometry; and statistics and probability. The content strands articulate the content to be taught while the proficiency strands describe how that content may be explored and developed. Each of the content strands has a number of sub-strands (two to six), which are developed across different year levels, as shown in Table 22:

Table 22 – Australian Curriculum: Mathematics strands and sub-strands (ACARA, 2015m)

Number and algebra	**Measurement and geometry**	**Statistics and probability**
Number and place value (F-8)	Using units of measurement (F-10)	Chance (1-10)
Fractions and decimals (1-6)	Shape (F-7)	Data representation and interpretation (F-1)
Real numbers (7-10)	Geometric reasoning (3-10)	N/A
Money and financial matters (1-10)	Location and transformation (F-7)	N/A
Patterns and algebra (F-10)	Pythagoras and trigonometry (9-10)	N/A
Linear and non-linear relationships (7-10)	N/A	N/A

Each of the content strands is described in its own paragraph and across the three a variety of skills are discussed. The ability of students to apply their understanding, use inductive and deductive reasoning, solve problems, develop arguments, analyse and interpret data, draw inferences, critically evaluate information, make reasoned judgements, and communicate effectively are all raised at least once (ACARA, 2015m).

Mathematics – Sequence of content. Years 7-10 (including the 10A) content descriptions and elaborations were examined. Content descriptions, as the name suggests, describe the content to be covered and thus do not focus greatly upon skills but instead stipulate the content to be learnt.

As the strands and sub-strands are each focused on a different branch of Mathematics, their content descriptions and elaborations are presented in the same way throughout. While they are very much focused upon specific mathematical knowledge to be developed, a range of skills is also noted or implied. Obviously many specific mathematical skills are to be developed, including: numeracy; the ability to perform calculations by hand as well as with appropriate technology; being able to estimate; communicate via algebraic notation, diagrams, graphs and words; collect, present and analyse data; and being able to select and apply appropriate techniques to solve problems. In addition to these specifically mathematical skills, a range of higher order thinking skills were also evident, with students needing to be able to: investigate, compare, justify approaches and/or findings, interpret, analyse and use deductive as well as inductive reasoning. There were minimal examples of what one might call genuine mathematical literacy, with only a few allusions to applying knowledge to real world scenarios.

Mathematics – General Capability tagging within Content descriptions and Elaborations. While the tagging of general capabilities and elaborations have already been presented by capability, the same information is now presented in a different way in Figure 30 to show how the general capabilities are referred to in the Mathematics content descriptors. The Mathematics curriculum has a large number of content descriptions (Year 7-10 average = 27.5, Year 7-10A average = 30.2) with relatively few elaborations (Year 7-10 average = 42.5, average of 1.5 elaborations/descriptor; Year 7-10A average = 47, average of 1.6 elaborations/descriptor). Year 10A was included as a fifth year category. However, as it is comprised of the tags from Year 10 as well as 10A, including it in the number of content descriptions/elaborations accounts for the small inflation of these averages.

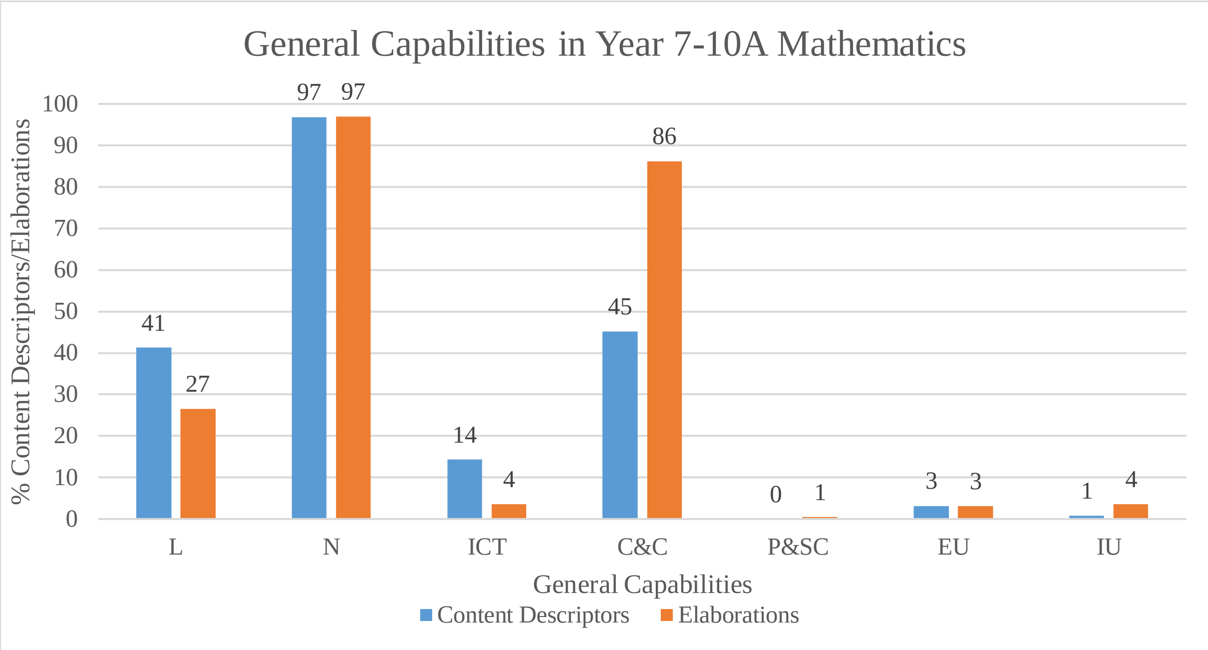

Figure 30 – Distribution of General Capability tags in Content descriptions and Elaborations across Year 7-10A Mathematics, L = Literacy, N = Numeracy, ICT = Information and Communication Technology Capability, C&C = Critical and Creative Thinking, P&SC = Personal and Social Capability; EU = Ethical Understanding; IU = Intercultural Understanding

Numeracy is the general capability that features overwhelmingly in Mathematics. Whilst only 45% of mathematics content descriptions are tagged with critical and creative thinking, 86% of its elaborations are, meaning many of the examples provided are tagged as such. Conversely, fewer elaborations than content descriptions present opportunity for development of literacy skills. Information and communication technologies are used as tools to complete calculations or present data and so on, while the last three capabilities are barely touched upon within the Mathematics curriculum.

Mathematics – Cross-curriculum Priorities. Despite the description of the cross-curriculum priorities indicating some ways in which they can be developed within Mathematics, there is little indication of this in so far as the tagging of content descriptions and elaborations, as shown in Figure 31.

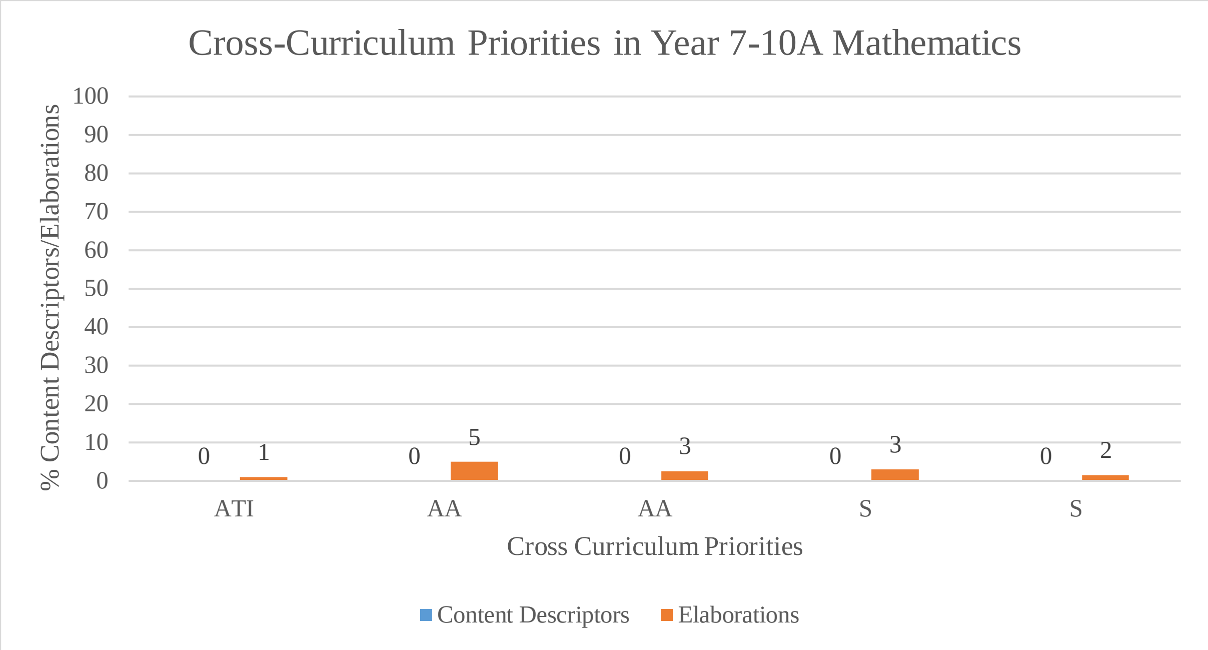

Figure 31 – Distribution of General Capability tags in Content descriptions and Elaborations across Year 7-10A Mathematics, ATI = Aboriginal and Torres Strait Islander Histories and Cultures; AA = Asia and Australia's Engagement with Asia; S = Sustainability

Given the complete absence of any tagging of content descriptions, and minimal tagging of elaborations, the chances of the cross-curriculum priorities being meaningfully addressed in Mathematics appear to be minimal., teachers are certainly not supported through the curriculum to do so.

Mathematics – Sequence of achievement. A subset of the skills identified in the content descriptions and elaborations is included within the achievement standards. The majority of these remain very content-focused in nature, with references being made to specific mathematical tasks students are to be able to perform. However, students are also to: solve problems; communicate with algebraic notation, as well as diagrams and in words; use deductive and inductive reasoning; and complete computations, either mentally or with technology. Students are also to be able to apply understanding and show higher order thinking skills such as making connections between ideas and being able to evaluate information and results (ACARA, 2015i).

Mathematics – Overall. Across the Mathematics curriculum, a wide variety of skills are highlighted. Some of these, such as the ability to apply understanding, mathematical and numeracy skills, critical thinking, reasoning, problem solving, and communication, are mentioned across each aspect of the curriculum. However, attributes such as confidence and self-motivation, and broader skills such as mathematical literacy feature in the rationale and/or aims of the learning area but nowhere else. Specifically mathematical skills, such as analysis (of data in particular), deductive and inductive reasoning, interpretation, investigation, calculation, mental arithmetic and so on feature more predominantly in the sequence of content and achievement standards and, in some cases, key ideas and structure. The focus within the curriculum is very much about the mathematical knowledge students will acquire and the mathematical skills they will develop. Higher order thinking skills and disciplinary skills pertaining to mathematics are found throughout, but references to literacy, interpersonal and intrapersonal skills are much less frequent.

Science – Rationale. Science is described as a discipline beyond school in terms of its broader aims, knowledge and nature. The learning area of Science is framed as one which will help students to draw evidence-based conclusions and thus make informed decisions. Curiosity, critical and creative thinking, the ability to use scientific methods and scientific literacy are all mentioned, as are attributes such as confidence and self-motivation (ACARA, 2015q).

Science – Aims. Seven aims are articulated via dot-points, some focus on an understanding of scientific processes as well as the historical and contemporary contributions to science to society and vice versa, whereas the majority focus on the skills and abilities the Science curriculum aims to ensure students develop. The ability to use various scientific methods is mentioned, as it was in the rationale, but is expanded to explain what this entails: questioning; planning and conducting experiments; collecting and analysing data; and evaluating results. Critical thinking skills, including evaluation and justification, are mentioned with a focus on using these skills to arrive at evidence-based decisions. Curiosity, the ability to select and integrate appropriate scientific knowledge and methods and use these to solve problems are all noted (ACARA, 2015o).

Science – Key Ideas. There are six key ideas that are embedded within each year level description. Each of these have a small, two paragraph description of what students are to learn about each of these ideas as they move through their science education. The six key ideas are as follows:

- patterns, order and organisation;
- form and function;
- stability and change;
- scale and measurement;
- matter and energy; and
- systems.

There are limited references to skills throughout the key ideas, with the focus being more upon how students' knowledge regarding these ideas will develop as they progress through school. However, a few skills are mentioned, such as: the ability to observe and describe patterns and trends (in nature, in data etc.); classification; quantifying change through measurement; conceptualisation of phenomena across a wide range of scales; and an increasing ability to understand abstract concepts (ACARA, 2015p).

Science – Structure. The science curriculum is comprised of three interrelated strands: science understanding; science as a human endeavour; and science inquiry skills, which together "provide students with understanding, knowledge and skills through which they can develop a scientific view of the world" (ACARA, 2015r, para. 2). It is emphasised that, just as the work of science involves an interrelationship between these aspects, that should be the experience of students at school also – thus the strands are not to be treated independently but integrated in a meaningful manner.

The science understanding strand is made up of four sub-strands which are each described by year level: biological sciences, chemical sciences, Earth and space sciences and physical sciences. Science as a human endeavour is described in two-year bands by two sub-strands: nature and development of science; and use and influence of science. In both of these strands, the focus is predominantly on what content students will learn rather than any skills they will develop at the same time (ACARA, 2015r). The third strand, science inquiry skills, is also described within two-year bands but has five sub-strands: questioning and predicting; planning and conducting; processing and analysing data and information; evaluating; and communicating. As suggested by the name, it articulates several skills which are to be developed within this strand. Students will develop skills in: identifying and constructing questions; proposing hypotheses; planning how to solve a problem/perform an investigation; collect, represent and analyse data and information; evaluate available evidence and come to evidence-based decisions; communicate in a range of forms utilised within science (ACARA, 2015r).

Science – Sequence of content. As there are three distinct strands within the Science curriculum, they will be presented one at a time.

Science understanding. The science understanding descriptors are all scientific statements which form the key content knowledge that students should know. There are one to three descriptors per sub-strand per year with Year 7 having six in total, Years 8 and 9 have seven and Year 10 has eight. Lower order thinking and some disciplinary skills, such as being able to investigate, classify, consider, group and use scientific conventions, are mentioned. However, the focus of these content descriptors is placed heavily upon the scientific content students are to know and understand.

Science as a human endeavour. Content descriptions for this strand are maintained across Year 7 and 8 with a new set being utilised for Years 9 and 10. However, the elaborations have been tailored for each year group so that examples of how these content descriptions can be addressed are provided within the context of that year's science understanding content. While this strand seeks to develop students' understanding of the nature and development of science as well as its use and influence, one may argue that the content of the strand will also further develop students' scientific literacy. Indeed the argument for the inclusion of nature of science to increase scientific literacy has often been made before (Allchin, 2011; McComas, Clough, & Almazroa, 2002). As in the science understanding strand, there is little other indication of specific skills to be developed.

Science inquiry skills. Similarly to science as a human endeavour, the content descriptions remain the same for two years at a time but the elaborations are adapted to suit each year group. This strand, as the name suggests, houses many skills relevant to science. A range of skills to be developed within this strand are articulated via the names of its five sub-strands: questioning and predicting; planning and conducting; processing and analysing data and information; evaluating and; communicating. Additionally, collaboration, selecting appropriate equipment, using ICT to present and analyse data as well as outcomes of research, describing patterns and trends, evaluating evidence, making evidence-based decisions are mentioned within the content descriptions of this strand (ACARA, 2015n).

Science – General Capability Tags in Content Descriptions and Elaborations. In the case of Science, there are relatively few content descriptions (an average of 19 across Years 7-10) but many elaborations (an average of 93 across Years 7-10, i.e. each content description has an average of five elaborations that provide examples of how they may be addressed). The distribution of general capability tags across both the content descriptions and elaborations was determined. The Year 7-10 tallied information is depicted in Figure 32.

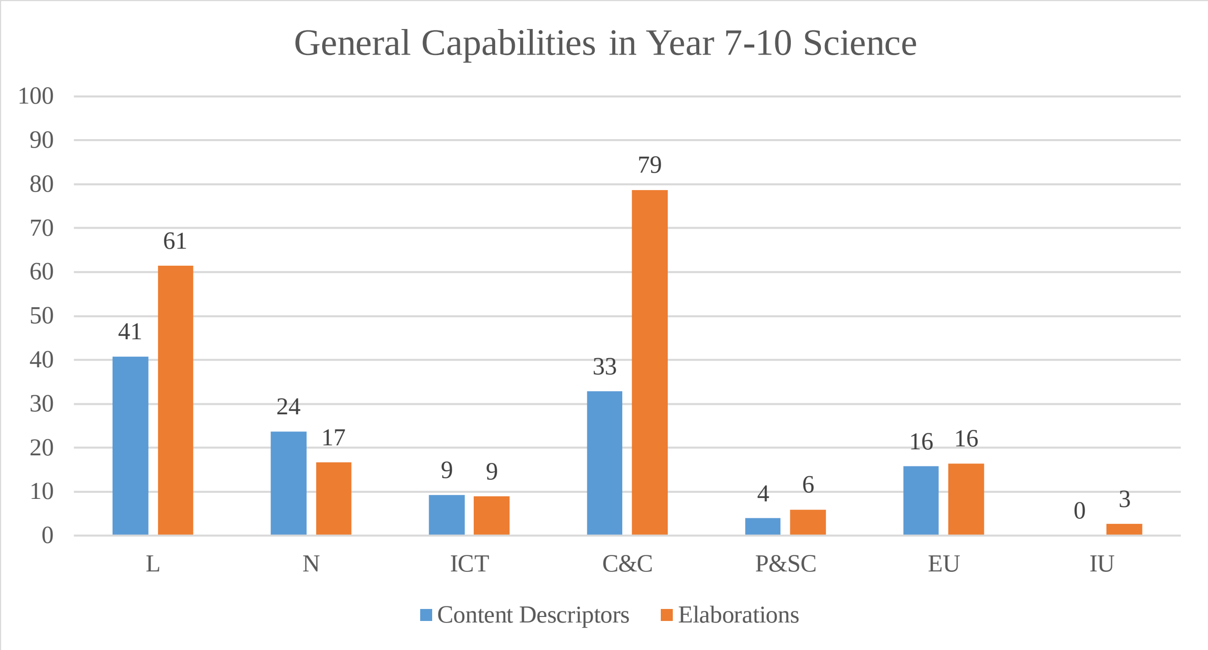

Figure 32 – Distribution of General Capability tags in Content descriptions and Elaborations across Year 7-10 Science, L = Literacy, N = Numeracy, ICT = Information and Communication Technology Capability, C&C = Critical and Creative Thinking, P&SC = Personal and Social Capability; EU = Ethical Understanding; IU = Intercultural Understanding (ACARA, 2015n)

It can be observed that while many general capabilities show a similar proportion of tags within content descriptions and elaborations, literacy (41 vs. 61%) and critical thinking (33 vs. 79%) are very different with a higher proportion of elaborations than content descriptions being tagged. In the case of critical thinking, this perhaps reconciles the unexpectedly low ranking (eighth out of eight) of Science within that general capability; the focus on critical thinking is given in the elaborations. It is important to note that the elaborations are not compulsory and not always read because teachers must navigate through the website to find them.

Science – Cross-curriculum Priority Tags in Content Descriptions and Elaborations. The very low degree of tagging pertaining to the cross-curriculum priorities is shown in Figure 33.

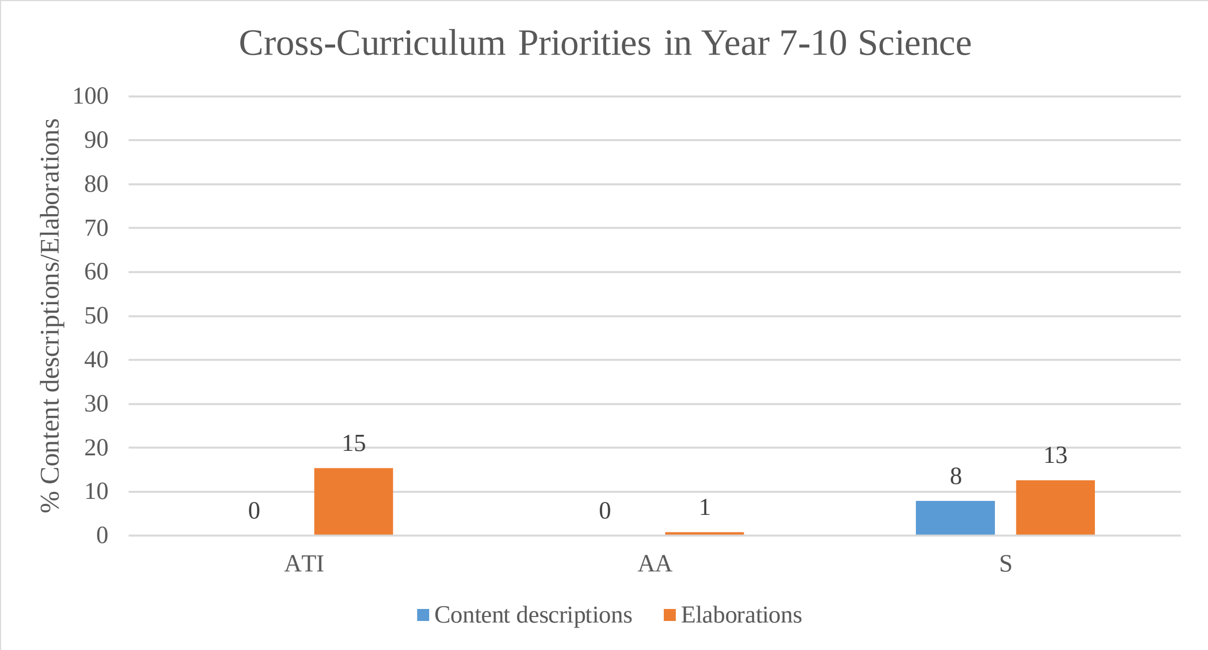

Figure 33 – Distribution of Cross-curriculum Priority tags in Content descriptions and Elaborations across Year 7-10 Science, ATI = Aboriginal and Torres Strait Islander Histories and Cultures; AA = Asia and Australia's Engagement with Asia; S = Sustainability (ACARA, 2015n)

The descriptions of the 'Aboriginal and Torres Strait Islander Histories and Cultures' as well as the 'Asia and Australia's Engagement with Asia' cross-curriculum priorities make reference to contexts in which these could be explored in Science. However, no content description is tagged as such. The proportion of elaborations tagged for Aboriginal and Torres Strait Islander Histories and Cultures has increased from 1% to 15% due to the additional elaborations added in Version 8.4, while only 1% of elaborations are tagged with the Asia and Australia's Engagement with Asia priority across Years 7-10. Sustainability fares better in content descriptions, as would be expected, but still has a low representation, with 8% of content descriptions and 13% of elaborations being tagged with the priority. These featured predominantly within the biological and Earth and space sciences components of Science understandings and the Science as a Human Endeavour strand of the Science curriculum (ACARA, 2015n).

Science – Sequence of achievement. The first of the paragraphs is essentially an assimilation of the science understanding and science as a human endeavour content descriptions, so there is minimal reference to skills beyond being able to describe, explain, analyse, classify and so on. The second paragraph summarises the science inquiry skills descriptors and thus mentions the skills previously outlined (ACARA, 2015n).

Science – Overall. Similarly to Mathematics, skills such as scientific literacy and attributes such as confidence and self-motivation feature in the rationale but do not appear again. Others, such as critical thinking, making evidence-based decisions, solving problems and the skills within the science inquiry skills strand feature throughout. Again, disciplinary skills and some higher order thinking skills are featured with little reference to literacy, interpersonal or intrapersonal skills.

Technologies – Overview. The Technologies is an example of a learning area made up of more than one subject. The Technologies learning area describes two distinct yet related subjects:

- "Design and Technologies, in which students use design thinking and technologies to generate and produce designed solutions for authentic needs and opportunities
- Digital Technologies, in which students use computational thinking and information systems to define, design and implement digital solutions" (ACARA, 2015t, para. 1).

The Australian Curriculum website has a rationale, aims and structure for the Technologies in general which are extended and complemented by more specific documents of the same name for each of the individual subjects. All three will be analysed here. The key ideas are only discussed for the Technologies in general. Each subject has a sequence of content but there is a sequence of achievement provided for the Technologies collectively as well as for each subject.

Technologies – Rationale. Overall. The rationale describes why it is an important learning area from a national perspective before moving onto a discussion around the learning experiences these two subjects provide for students and the skills they will develop. The value of this subject for students in their future lives is reinforced by framing the learning area within the context of students becoming enterprising young Australians, capable of making choices and contributing to society in an ethical and sustainable manner. Being able to think critically as well as creatively to solve complex problems, either individually or collaboratively, was highlighted along with engaging in design and systems thinking, prototyping and evaluating solutions (ACARA, 2015t).

Technologies – Rationale. Design and Technologies. This rationale follows a similar structure to that of the Technologies, first highlighting the importance of knowledge and skills regarding the design, development and use of technologies before moving into a more specific discussion of the subject matter itself. There is a strong focus on students considering a whole range of factors and impacts beyond those merely required for design. For example, economic, environmental, ethical, legal and social facets. It also highlights the fact that skills learnt within Design and Technologies may be transferred to home, leisure activities, the broader community and the workforce. The same types of skills are noted in this description as outlined above but with a greater focus on the design process and the hands-on skills required within the subject to design and create design solutions. There are some overtures towards what may be called technological literacy or even STEM literacy in that there is a clear focus on the use of design to solve real-world problems in a sustainable manner (ACARA, 2015c).

Technologies – Rationale. Digital Technologies. The importance of this subject is given in terms of the ever-increasing digitisation of the world and the heavy reliance of many facets of society on digital systems. A description of the knowledge and skills developed by this subject is given, as well as how it will contribute to students becoming active and ethical global citizens. Many of the same skills are indicated again, but this time with a greater focus upon technological literacy, digital skills such as programming and technology design, and communication. Solving problems with creative solutions independently or collaboratively are again a feature (ACARA, 2015g).

Technologies – Aims. Overall. The aims of the Technologies are distilled into five dot-points, prefaced with the fact that this learning area seeks to develop students who can work both independently and collaboratively. Students will be given the opportunity to evaluate needs and/or opportunities when designing a solution to a particular problem. Students are to be encouraged to develop their skills in innovation and entrepreneurship so that they can become confident designers who are technologically literate and capable of making informed, ethical and sustainable decisions (ACARA, 2015t).

Technologies – Aims. Design and Technologies. In addition to what was outlined overall, there are six aims within the Design and Technologies curriculum. There is a great deal of overlap in terms of the skills articulated already. There is an addition of design and systems thinking, the practical skills required to choose and utilise the appropriate equipment safely and manage ongoing processes, as well as being able to transfer knowledge and skills to new situations (ACARA, 2015b).

Technologies – Aims. Digital Technologies. The skills outlined in the overall and Design and Technologies aims are again featured, with the addition of computational and algorithmic thinking, and being able to deal with abstraction, collect, display and interpret data (ACARA, 2015f).

Technologies – Key ideas. The Technologies have the overarching idea of 'Creating preferred futures' under which lies Project Management, Thinking in Technologies (Systems thinking, Design thinking and Computational Thinking), Safety and Animal ethics. While the key ideas of Mathematics and Science focused upon knowledge, the Technologies' key ideas highlight disciplinary skills which will be developed. The Technologies key ideas as a whole focus much more on processes than specific content to be covered.

The learning area provides many opportunities for students to utilise critical and creative thinking skills in identifying a need or opportunity, and going through the process of how to design and evaluate possible solutions. Students are given the opportunity to manage long-term projects, which requires good planning and organisation as well as time management skills. There is a strong focus upon systems, design and computational thinking and how they are utilised in the problem solving process. Being able to use and develop ICT tools using skills such as programming are also central, particularly within Digital Technologies (ACARA, 2015u).

Technologies – Structure. Overall. The Technologies learning area from Foundation to Year 10 is made up of two subjects, Design and Technologies and Digital Technologies, with the intention that all students will study both subjects from Foundation until the end of Year 8. In Years 9 and 10, school authorities determine student access to the Technologies learning area. This might include the study of these subjects as outlined by the Australian Curriculum and/or specific contexts as determined by state and territory authorities. The two subjects are structured such that their individual differences may be taught whilst also enabling them to be taught as part of an integrated teaching program that covers both subjects, and other learning areas also if desired by the teacher, particularly in the Primary years. The curriculum for both Technologies subjects is written in bands, the first being Foundation to Year 2 and the rest comprising two-year levels. Two related strands describe each subject: knowledge and understanding; and processes and production skills (ACARA, 2015v), as shown for each of the subjects in Table 23.

Table 23 – Design and Technologies and Digital Technologies content structure (ACARA, 2015v)

Design and Technologies	**Digital Technologies**
Knowledge and understanding	
Technologies and society • the use, development and impact of technologies in people's lives Technologies contexts • technologies and design across a range of technologies contexts	Digital systems • the component of digital systems: hardware, software and networks and their use representations of data • how data are represented and structured symbolically
Processes and production skills	
Creating designed solutions by: • investigating and defining • generating and designing • producing and implementing • evaluation • collaborating and managing	Collecting, managing and analysing data Creating digital solutions by: • investigating and defining • generating and designing • producing and implementing • evaluation • collaborating and managing

It is noted that this common strand structure facilitates integrated approaches. "Teachers can select technologies-specific content from the Knowledge and understanding strand and students can apply skills from the Processes and production skills strand to that content" (ACARA, 2015v, para. 7). Table 23 clearly shows the key production skills that will be developed within the two subjects.

Technologies – Structure. Design and Technologies. This section elaborates on the technologies contexts that teachers may select to use as a framework for students to develop knowledge, understanding and skills: engineering principles and systems; food and fibre production; food specialisations; and materials and technologies specialisations. Teachers and schools are to provide Foundation to Year 8 students with "the opportunity to produce at least three types of designed solutions (product, service and environment) through the technologies contexts identified for a band" (ACARA, 2015d).

The last part of this document examines the Design and Technologies processes and production skills and elaborates on each of the five points under Processes and production skills as outlined in Table 23. Here a range of higher order thinking skills, such as critiquing, critical and creative thinking, evaluation, justification and synthesis are discussed. Specific design skills, such as modelling, prototyping, graphical representation techniques and production skills are discussed, as is the need to be able to collaborate and manage time and resources when designing solutions to problems (ACARA, 2015d).

Technologies – Structure. Digital Technologies. Comments are made regarding how the two strands (Table 23) are related and the key concepts underlying each are highlighted. Under the first strand resides digital systems and representation of data, in which students acquire the key knowledge and understanding they will need to create digital solutions. Within the second strand there are some features that are developed from Foundation to Year 10, while others are developed within specific year levels. The importance of computational thinking is also highlighted, this is described as "a process of recognising aspects of computation in the world and being able to think logically, algorithmically, recursively and abstractly" (ACARA, 2015h, para. 10).

The key concepts underlying the Digital Technologies curriculum are: abstraction; data collection, representation and interpretation; specification, algorithms and implementation; digital systems; and interactions and impacts. Types of digital solutions are also discussed ranging from hardware and software applications to instructions provided via programming (ACARA, 2015h).

Technologies – Sequence of Content. Design and Technologies. The Design and Technologies content descriptions are arranged under the two strands identified in Table 23. The

Knowledge and Understanding content descriptions, which one might assume to merely contain things students need to know (as in Mathematics and Science), are instead phrased in quite a practical way, with the elaborations demonstrating a variety of ways one may address this content description in a hands-on manner. The Processes and Production Skills content descriptions are skills based and outline the processes students need to work through in the production of whatever happens to be the focus of their current context of exploration.

Throughout the content descriptions a wide variety of skills and attributes are highlighted. Design and Technologies provides students with occasions to identify needs and opportunities around them and to identify a problem for which to create a design solution. This enables them to develop project and time management skills along with the technical skills they will need to create whatever is required for their solution. The design process can be used as a scaffold to help students to develop their design thinking, to investigate options, experiment and use models or prototypes in testing designs, make ethical and sustainable decisions about material choice, and the long-term impact of their solution. Along the way students will have to critique, analyse and evaluate their solutions, communicate clearly, and apply critical and creative thinking skills when working independently as well as with others. Whilst not explicitly stated, students can be given opportunities within the course to develop their technological and engineering literacy skills (ACARA, 2015a).

Technologies – Sequence of Content. Digital Technologies. The Knowledge and Understanding content descriptions for Digital Technologies are somewhat more like the Mathematics and Science ones than Design Technologies in that they focus more on the specific knowledge students are to develop. The Processes and Production Skills content descriptions are more similar to the Design and Technologies ones, outlining a range of things students need to be able to do and the skills they will need. Many of the skills outlined are very specific to the subject and there are many parallels with the ICT general capability, though the focus now is on the design of digital tools as well as how to use them. Students need to be able to acquire, analyse and visualise data, use computational and algorithmic thinking, and use models and programming to create digital solutions. As in the case of Design and Technologies students will critically evaluate their solutions and will be involved in ongoing projects, often requiring collaboration (ACARA, 2015e).

Design Technologies – General Capability Tagging in Content Descriptions and Elaborations. The distribution of tags within Year 7&8 and Year 9&10 Design and Technologies is shown in Figure 34. There is an average of 11 and 56 respectively, so an average of just over five elaborations per content description.

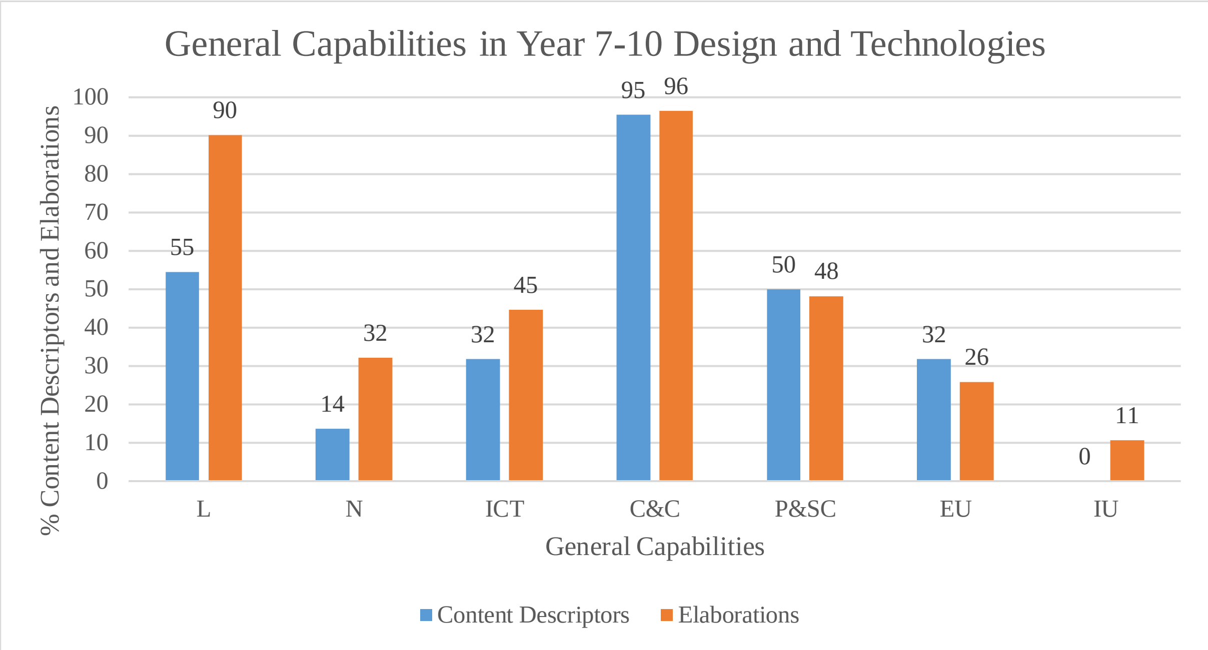

Figure 34 – Distribution of General Capability tags in Content descriptions and Elaborations across Year 7-10 Design and Technologies, L = Literacy, N = Numeracy, ICT = Information and Communication Technology Capability, C&C = Critical and Creative Thinking, P&SC = Personal and Social Capability; EU = Ethical Understanding; IU = Intercultural Understanding

Figure 34 shows that Design and Technologies present a more well-rounded opportunity for the integration of the general capabilities than Mathematics or Science, with all except intercultural understanding having a good representation in content descriptions as well as elaborations.

Digital Technologies – General Capability Tagging in Content Descriptions and Elaborations. The overall distribution of tagging of content descriptions and elaborations for Digital Technologies is shown in Figure 35. Similarly to Design and Technologies, there was an average of 11 content descriptions and 51 elaborations, so a slightly lower average of a little under five elaborations per descriptor.

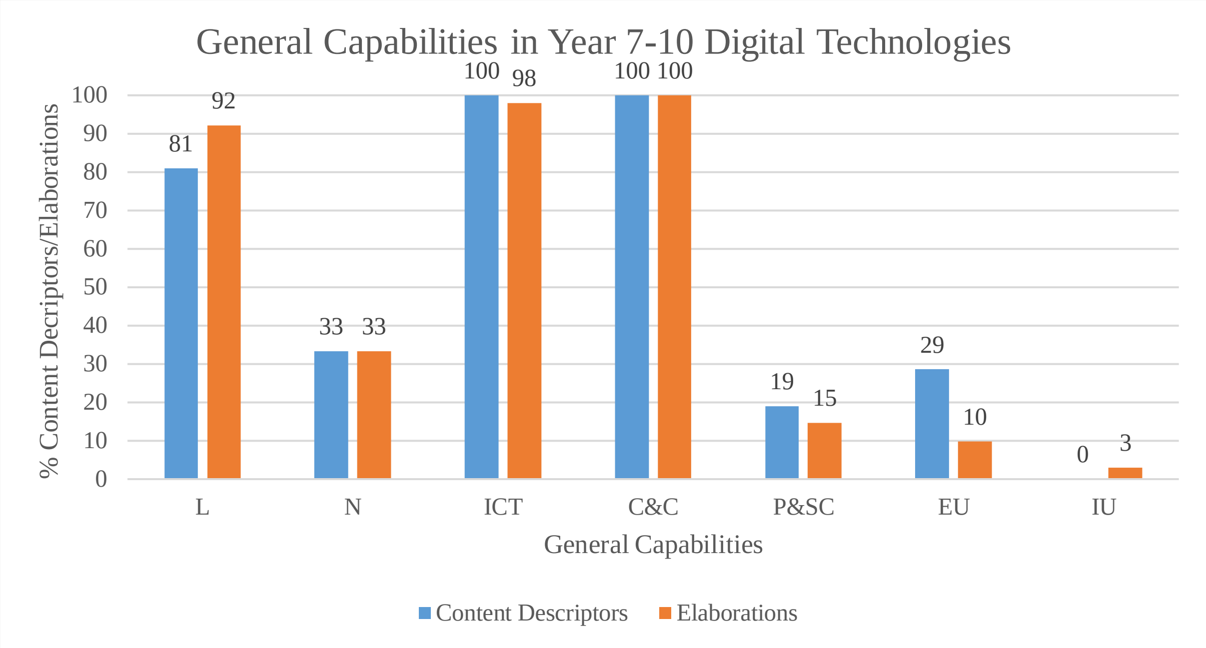

Figure 35 – Distribution of General Capability tags in Content descriptions and Elaborations across Year 7-10 Digital Technologies, L = Literacy, N = Numeracy, ICT = Information and Communication Technology Capability, C&C = Critical and Creative Thinking, P&SC = Personal and Social Capability; EU = Ethical Understanding; IU = Intercultural Understanding

Digital Technologies clearly has ample opportunity for the development of literacy, ICT and critical and creative thinking in particular. Tags for personal and social capability as well as ethical understanding were less prolific for Digital Technologies than they were for Design Technologies, possibly due to the strong focus on preferred futures of the Design and Technologies subject. Again, intercultural understanding is barely addressed.

Technologies – Sequence of achievement. There is an achievement standard for the learning area as well as for each subject in Years 7 and 8, but only an achievement standard for each subject in Year 9 and 10 as Design Technologies and Digital Technologies are now optional. Collectively, the achievement standards highlight skills such as being able to:

- evaluate needs and opportunities in order to create design ideas and develop solutions;
- engage in design, systems and computational thinking;
- manage ongoing projects
- make adjustments to solutions as required
- select and use the appropriate technologies for a given task
- to analyse and evaluate data, use programming language;
- to communicate with different audiences in person and online;
- and to work effectively individually as well as collaboratively (ACARA, 2015e).

Technologies – Overall. A much broader range of skills are articulated throughout the Technologies curriculum than was the case in Mathematics and Science. It is clearer to see how technological literacy, engineering literacy and arguably even STEM literacy may be meaningfully developed through these subjects. This is because they are focused upon providing solutions to real world problems, generally in a manner which requires the integration of knowledge and skills from a range of disciplines. As these are such practical subjects, many subject-specific technical skills are highlighted. Higher order thinking skills, especially critical and creative thinking but also analysis, evaluation and problem solving are also frequently mentioned. Attributes such as flexibility, required when one must change a design, and self-motivation to see a project through to the end, are also valued in this learning area. Finally, being able to work independently as well as collaboratively and to communicate clearly in a variety of forms for a variety of audiences is specifically stated. The Technologies learning area, and Design and Technologies in particular, present a plethora of opportunities for students to engage in STEM learning as the learning area naturally draws together aspects from different disciplines as required to solve a problem.

How does the Australian Curriculum fulfil the aims of science, and STEM, education? Before concluding Part 2a, it is worth reflecting on the aims of science education as articulated by (Fensham, 2004) in Chapter 2, how they are addressed by the Science curriculum, and how it is complemented by the Mathematics and Technologies curricula. It could be argued that the ‘Science as a Human Endeavour’ strand aims to help to prepare students to “participate fully in political and social choices facing a technological society” (Fensham, 2004, p. 9), particularly through the use and influence of science sub-strand. This is complemented by the Technologies curriculum in which students are given greater opportunity to focus on technologies and the impact of design decisions on society. The second aim, to prepare interested students for further education in science (Fensham, 2004), is well covered by the science understanding strand as well as by the mathematics and technologies curricula.

In terms of preparation for modern fields of work (Aim 3), the mathematics and science curricula tend to focus predominantly on developing students’ knowledge of what they would require for future study rather than life in general. The ‘Science as a Human Endeavour’ strand makes some overtures towards developing scientific literacy for all, not just future scientists. However, many teachers have noted that they require assistance in authentically incorporating this strand within their teaching (Logan, 2012).

Finally, in terms of stimulating “intellectual and moral growth of students” (Fensham, 2004, p. 8), the lack of focus on a general capability such as ethical intercultural understanding within the Mathematics and Science curricula, along with their general tone and focus, means that there is little evidence in the curriculum document itself that this may be achieved. The better representation of ethical understanding within Technologies, as well as Technologies' focus on sustainability and the impact of decisions means the fourth aim may be partially achieved via this learning area.

As an overall summation and response to Research Question 2a, the domains of STEM skills as identified in Part 1a of Chapter 5 are developed to varied degrees across the Australian Curriculum. While mathematical and scientific literacy are touched upon in the opening parts of the learning area, they do not feature strongly in content descriptions or achievement standards and are therefore unlikely to be a focus area for teachers. Technological and even STEM literacy may be able to be more meaningfully developed in the Technologies. Relevant disciplinary skills were a focus of each learning area, as were a subset of the higher order thinking skills. Interpersonal and intrapersonal skills, again whilst often mentioned in the opening sections of curricula, were not a focus within Mathematics or Science, but were much more meaningfully included in the Technologies. The Technologies appears to be an ideal learning area through which to develop a wide range of STEM skills as it is driven by skills rather than content knowledge.

Research Question 2b – To what extent do Australian year 7-10 STEM teachers feel the Australian Curriculum supports them in developing STEM skills in their students?

Demographics of respondents to Section 4 of the survey discussed in Chapter 6

Only 91 respondents completed the component of the survey pertaining to the Australian Curriculum as it was an optional component. This is because the Australian Curriculum was not mandated for all STEM learning areas in all states and territories during 2017, the year the survey was conducted. As a result, to help determine the extent to which the findings can be relied upon in drawing general conclusions, a range of demographic factors for this subset of respondents were examined.

Biological Sex. As was the case for the respondents overall, there was skew towards females. However, the degree of the skew was almost identical, with 69% of respondents overall and 70% of Section 4 respondents being female. This remains higher than the proportion of female teachers nationwide which is 59.2% (Freeman et al., 2014).

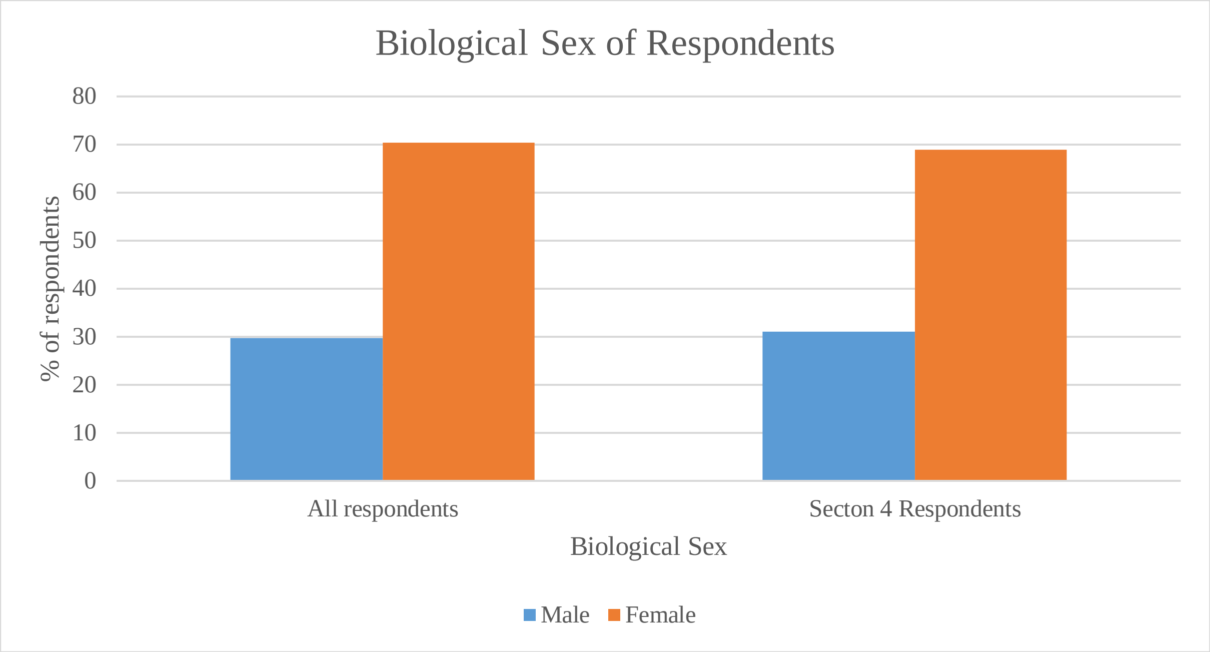

Figure 36 – Biological Sex of respondents to the complete survey (n = 145) versus Section 4 respondents only (n = 91)

Age of Respondents. The age of respondents was similar for the whole survey when compared with those completing Section 4, with the as shown by Figure 37.

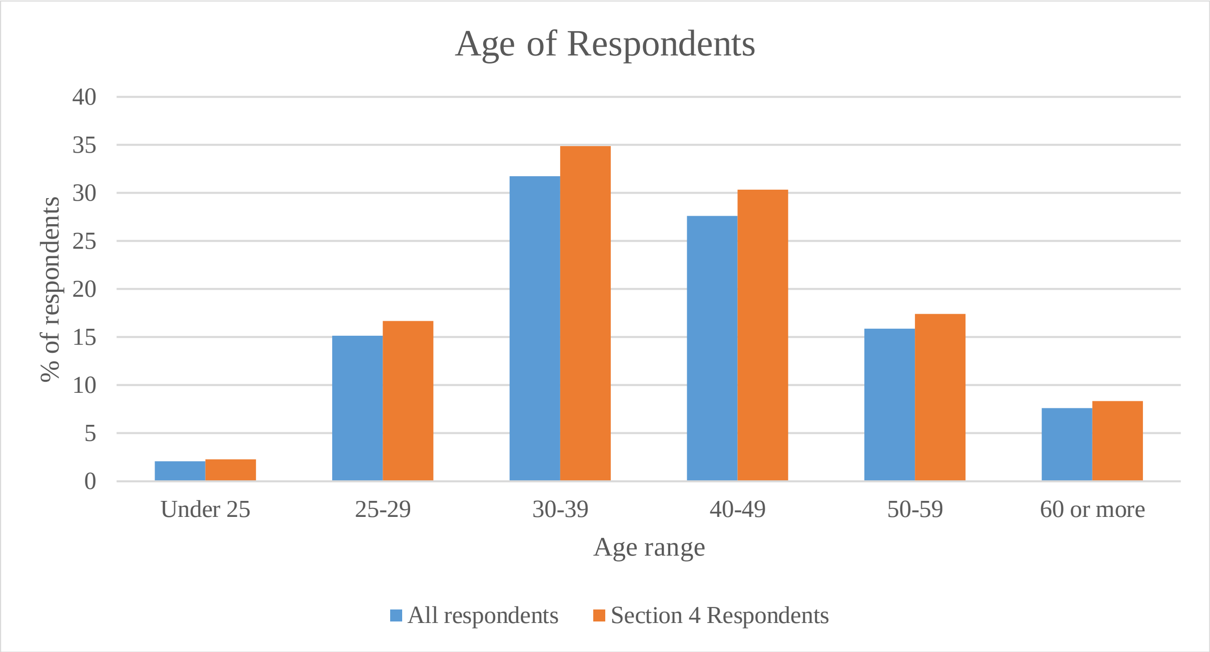

Figure 37 – Age of respondents for the complete survey (n = 145) versus Section 4 respondents only (n = 91)

Years spent teaching. The years spent teaching among all respondents as opposed to Section 4 respondents alone are also essentially the same, as shown in Figure 38.

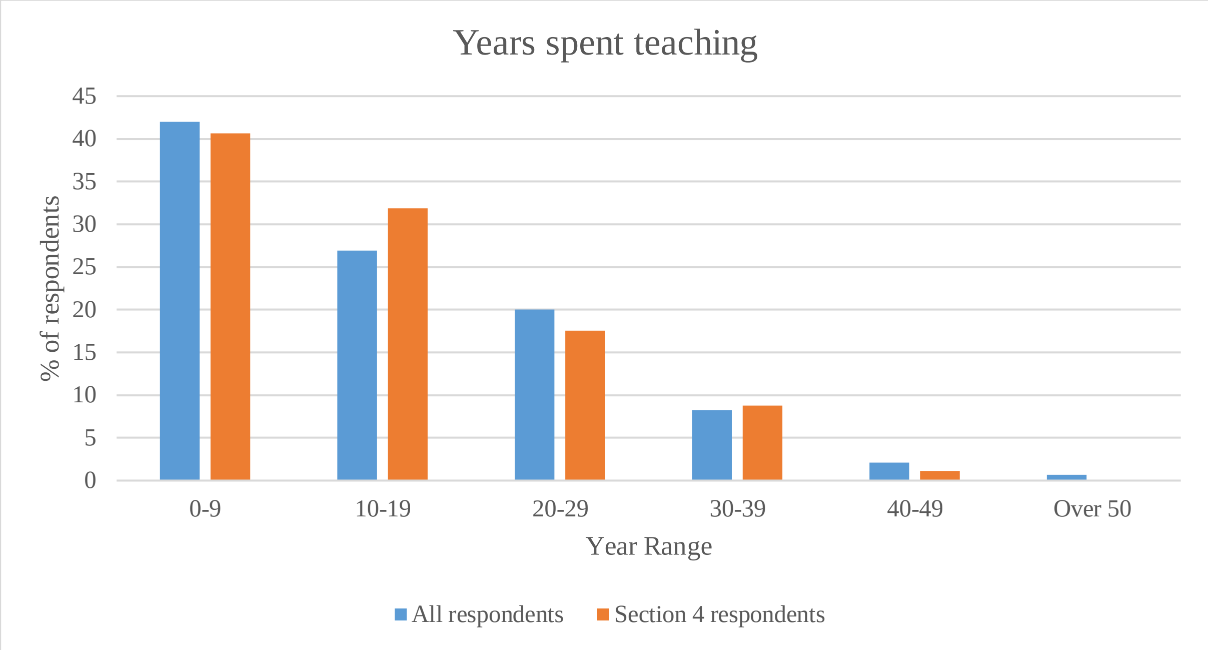

Figure 38 – Distribution of number of years spent teaching among all respondents (n = 145) versus Section 4 respondents (n = 91)

This further indicates that the respondents of Section 4 are a fair representation of the respondents of the survey as a whole and thus a good representation of the Australian teaching population in terms of these demographic factors.

Geographic location of the school. While it has been shown that the respondents of Section 4 were very similar to the respondents to the survey on the whole, the different implementation schedules of the Australian Curriculum across the country (ACARA, 2014c) made it likely that the state or territories from which the Section 4 respondents came would differ from those of the survey as a whole. This was demonstrated to be the case, as shown by Figure 39.

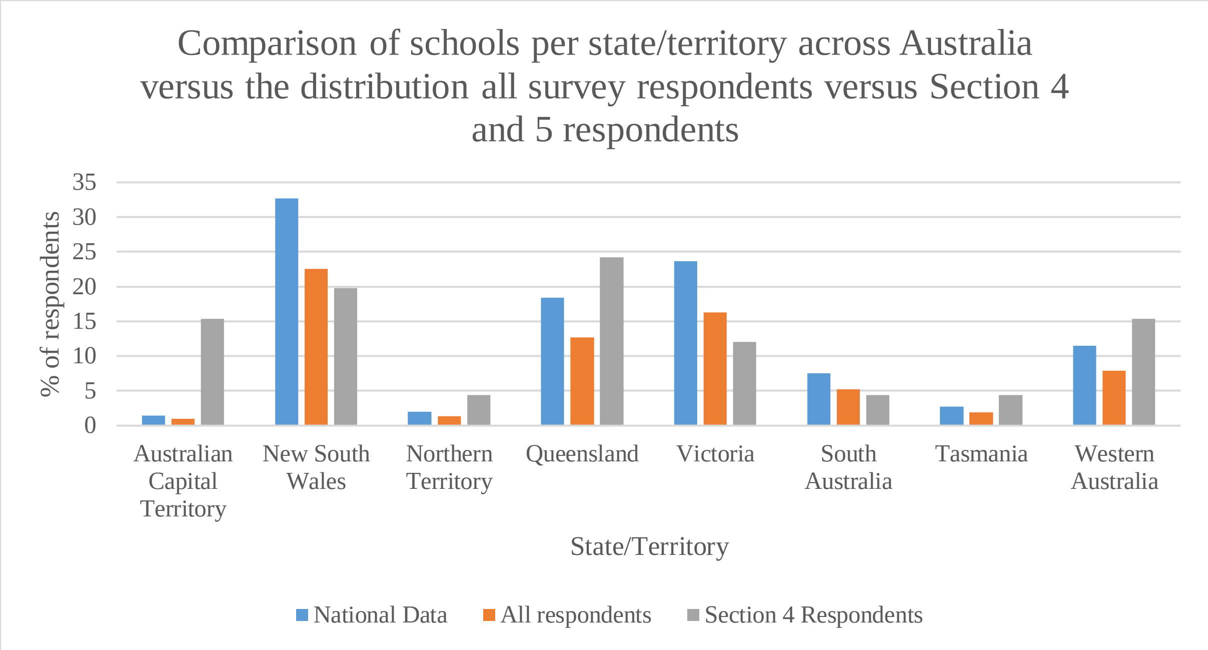

Figure 39 – Comparison of schools per state/territory across Australia (ABS, 2018c) (n = 9444) versus the distribution of all survey respondents versus Section 4 respondents (n = 91)

The geographic location of the schools from which the respondents as a whole versus the respondents of Section 4 represents the greatest demographic difference. This is because each state and territory implemented the Australian Curriculum upon its own timeline. Unsurprisingly, the ACT and QLD, the first two jurisdictions to enforce the Australian Curriculum, were the most heavily over-represented in Section 4 in comparison with the respondents of the complete survey (ACARA, 2014c).

Section 4 – Teacher familiarity with the components of the Australian Curriculum

As the Australian Curriculum was being analysed as part of the broader study, teacher familiarity with various components of the curriculum was determined via the survey. Figure 40 shows a series of stacked boxplots indicating teacher familiarity with various aspects of the Australian Curriculum.

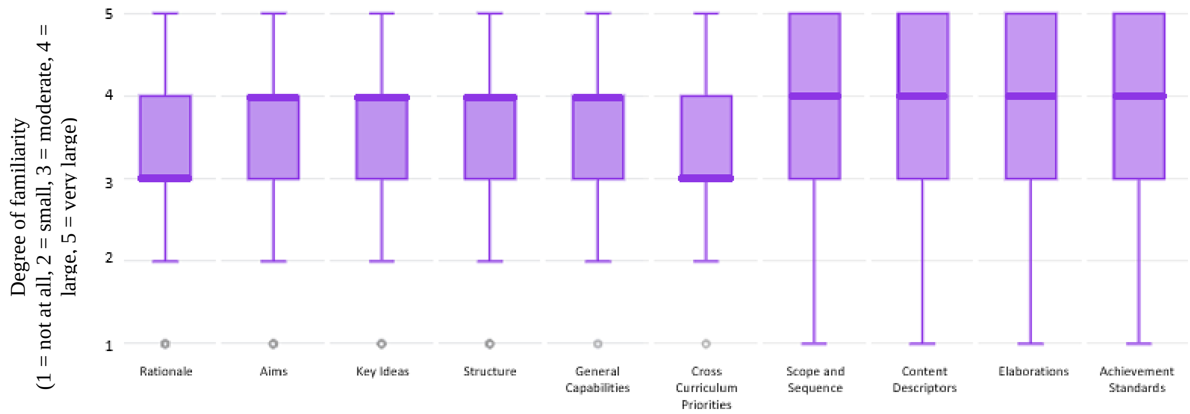

Figure 40 – Boxplots showing relative degree of familiarity with various aspects of the Australian Curriculum.

Note: The dots on the horizontal line across the bottom represent outliers, the horizontal bar at the end of the whiskers indicates the minimum/maximum value (excluding outliers). The median is the thick line in the centre of the box except in cases where the second or third quartile are equal to the median. For cases in which there is no upper whisker, the third quartile is equal to the maximum value.

Each of the aspects of the curriculum were unfamiliar to and very familiar to at least one teacher. The first six aspects of the curriculum in Figure 40, the rationale through to the cross-curriculum priorities, each have a very small interquartile range and so those teachers who indicated that they were not at all familiar with those aspects of the curriculum were outliers, lying more than one-and-a-half times the interquartile range below quartile two, represented by dots. The rationale and cross-curriculum priorities were the aspects with which respondents were least familiar as 50% of respondents had a moderate or lower degree of familiarity. This is perhaps because the rationale is listed some distance from the sequence of content and, as previously demonstrated, the cross-curriculum priorities are poorly flagged across STEM learning areas and are therefore likely to be less familiar than the general capabilities. The aims, key ideas, structure and general capabilities were better understood with 50% of respondents having a large degree of familiarity or lower. The scope and sequence, content descriptors, elaborations and achievement standards showed the most spread, with the interquartile range being sufficiently large to preclude any outliers. The median for these aspects indicated a large degree of familiarity, with a significant proportion of respondents having a large or very large degree of familiarity. Having examined familiarity with each section of the curriculum in Figure 40, particular components will be focused upon one at a time in the following figures.

The rationale, aims, key ideas and structure are something of a prelude to the presentation of material to be taught within a subject. Figure 41 depicts how many teachers responded with what degree of familiarity to those aspects of their subject.

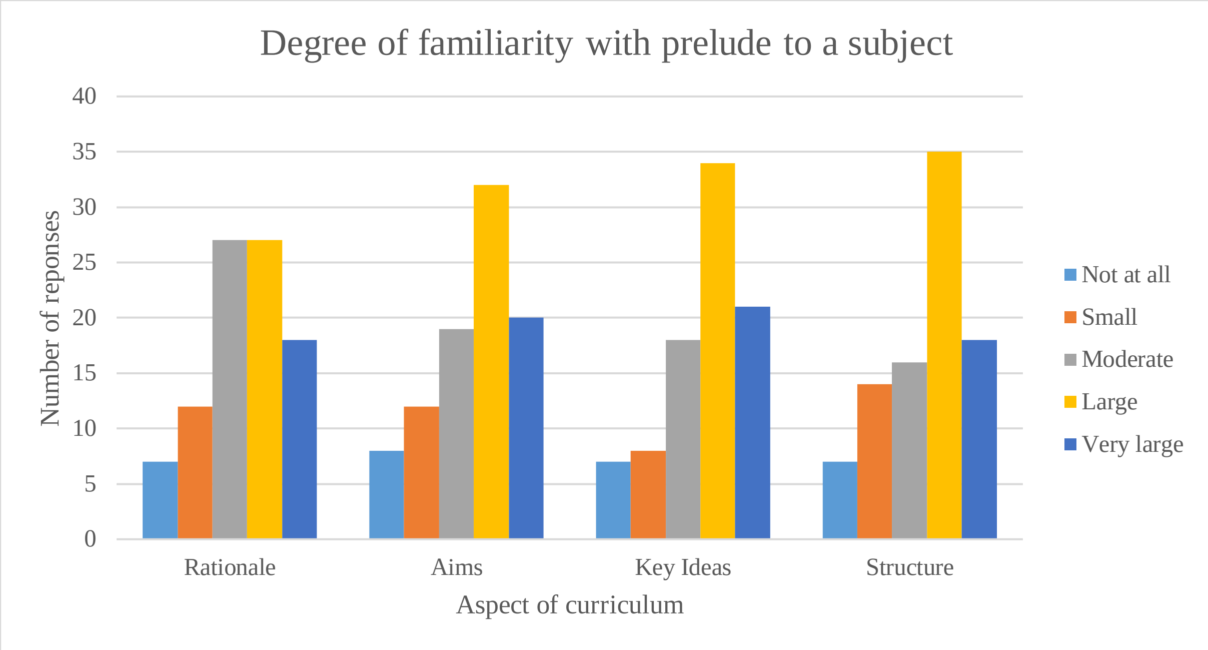

Figure 41 – Degree of familiarity with documents which form the prelude to a subject within the Australian Curriculum

There is a negative skew for each of the components of the curriculum, indicating that teachers on the whole had a good awareness of these components of the curriculum. As shown in Figure 40, teachers are less familiar with the rationale but have similar degrees of familiarity across the aims, key ideas and structure of the subject they teach.

Figure 42 shows teachers' degree of familiarity with the details of the content of the subject in terms of its scope and sequence as students move through the year levels, the content descriptions, elaborations and the achievement standards.

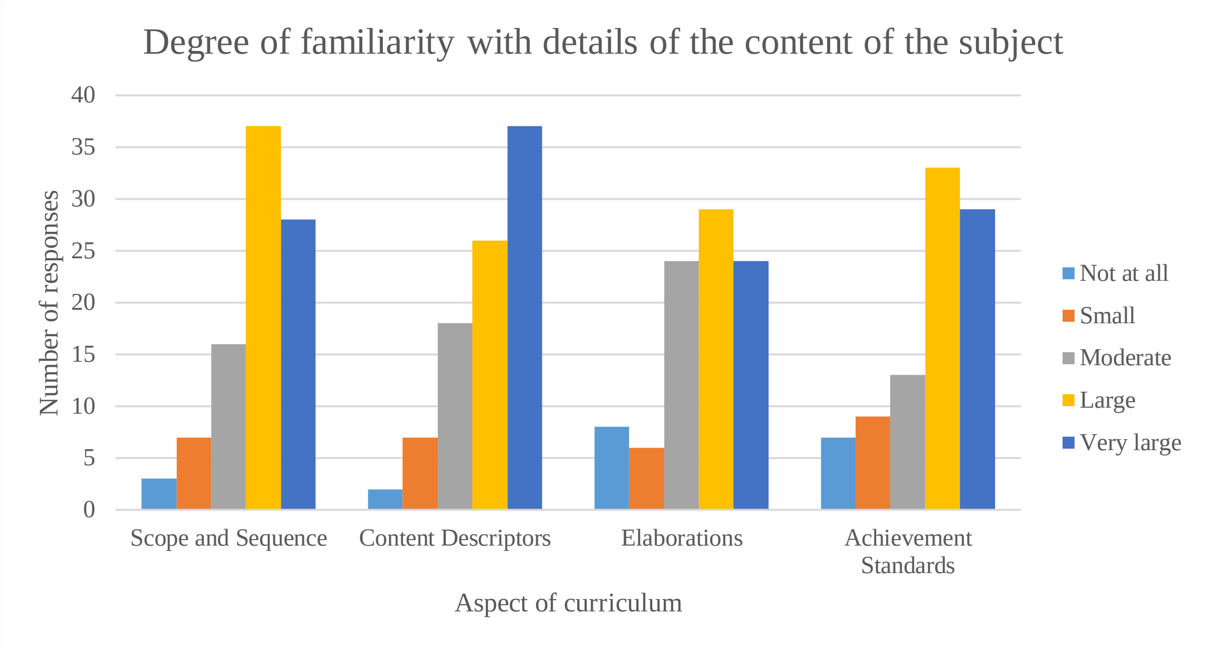

Figure 42 – Degree of familiarity with the details of the content of a subject within the Australian Curriculum

Teachers reported greater familiarity with these aspects of the curriculum than the rationale etc. This is perhaps to be expected as the components shown in Figure 42 account for the day-to-day teaching and learning that needs to be achieved. Familiarity with the scope and sequence, content descriptions and achievement standards were highest. This is perhaps because they are presented together and tie together strongly. The elaborations are optional so lower familiarity with them is not particularly problematic.

There were several teachers with no or only a small degree of familiarity with the scope and sequence, content descriptions and achievement standards. This relative lack of familiarity is a problem because teachers need to report on students' progress against achievement standards, and their courses should be planned around the content descriptions in line with the scope and sequence. However, it could exacerbated by the fact that individual teachers in some schools are not expected to directly engage with the curriculum website, or their State/Territory version of it. One respondent commented,

> I am part of a faculty where our learning programs have been carefully crafted by our faculty coordinator and the Year 9 team. At the time of the AC [Australian Curriculum] introduction, I was teaching outside the faculty. I have engaged with the AC only through the teaching programs that have been prepared.

This is not an uncommon arrangement within schools, where curriculum leaders engage directly with the document and tailor it to their school context. However, it could be argued that all teachers should at least know that this support exists and be encouraged to consult the curriculum directly to gain a better understanding of the intent and structure of the curriculum as a whole. For instance, one teacher said "I do not know what the achievement standards are", which is concerning as they are arguably the most important component of the curriculum in terms of guiding teaching and learning. This is because they state what the students should be able to do and know by the end of the year. One teacher, though, indicated they knew what support was available and referred to it as needed, "If I am not sure I look them up. I frequently use the website as a source of information in these areas."

Finally, Figure 43 shows the degree of familiarity with the general capabilities and cross-curriculum priorities. As these two strands overlay all subjects of the curriculum they have been presented separately from subject specific aspects.

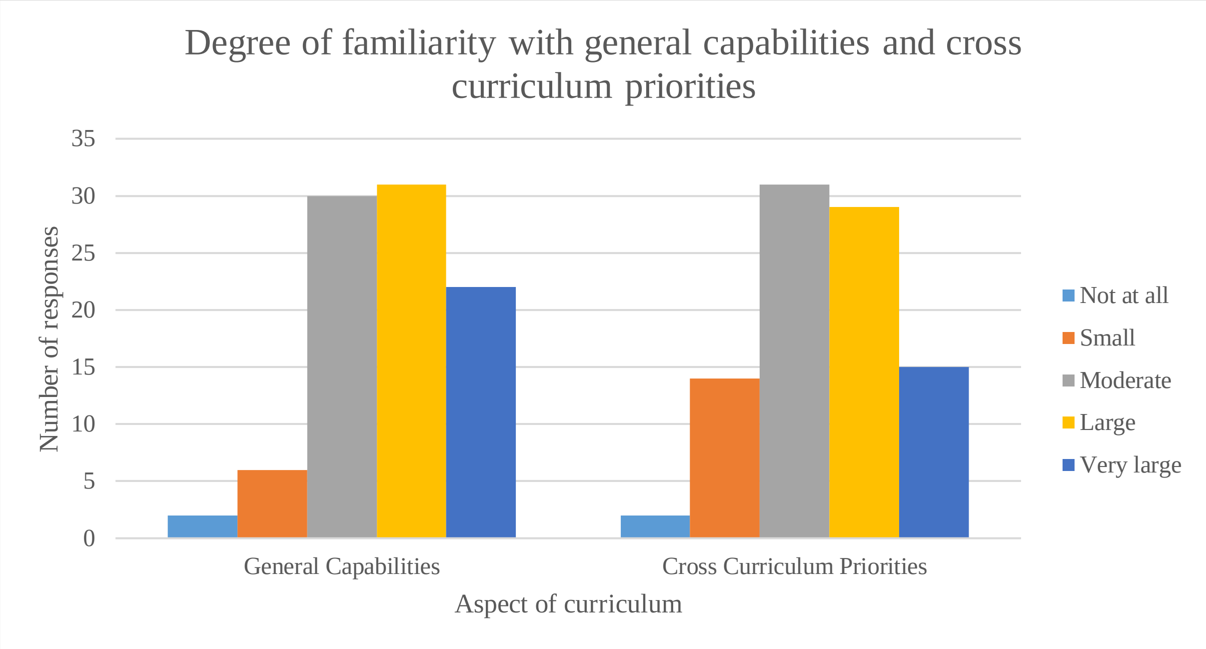

Figure 43 – Degree of familiarity with the General Capabilities and Cross-curriculum priorities of the Australian Curriculum

The distributions of familiarity with these two aspects of the curriculum are very similar. Only two teachers knew nothing about them while significantly more teachers had limited awareness of the cross-curriculum priorities as opposed to the general capabilities. This was mirrored by more teachers having a high level of knowledge of the general capabilities with fewer being as familiar with the cross-curriculum priorities. One teacher noted "Knowing and being able to do something about it are two very different things", indicating that while teachers might know about these important aspects of the curriculum, they are not necessarily incorporating them within their classes. This is vital to remember, not just in terms of these aspects of the curriculum, but the curriculum in general. Many things can happen between a curriculum document and the classroom.

Section 5 – Teacher perspectives

The last question asked teachers who are implementing the Australian Curriculum for their opinion on the extent to which the curriculum supports the development of STEM skills. The median levels of familiarity with each aspect of the Australian Curriculum of respondents answering this question were found to be equal to or greater than the level of familiarity with respondents as a whole. This indicates that the comments about the extent to which the curriculum supports the development of STEM skills are being made by people who are more familiar with the curriculum. This lends increased weight to their comments. There were 88 comments made in total, with two thirds of these pertaining to Science.

Science. The Australian Science curriculum was deemed to provide little support for the development of STEM skills by 44% of respondents. Some of these teachers indicated that certain skills were supported better than others and highlighted issues such as skills being developed within subject siloes and are not transferred between learning areas. However, the most frequently cited issue was lack of time to develop skills. This lack of time was primarily attributed to the overabundance of content in the curriculum. Some teachers indicated that relatively few skills were explicitly stated within the curriculum and felt that there is a litany of content to cover. Comments such as those below were common,

It includes too much knowledge base to have time to include more open-ended creative learning

Too much content to cover

The amount of content in the curriculum often overrides the focus on skills

The sentiment of the Australian Curriculum being overcrowded is a common one (Australian Government Department of Education, 2014; Hunter, 2018). However, it can be argued that this is not the case. After all, the number of content descriptors in the Science curriculum are few and the elaborations are not compulsory. It depends on one's interpretation of how the curriculum is to be covered. This group of respondents indicated that some skills, such as engineering and technological literacies, were difficult to effectively develop within Science. It was also commented that there was generally insufficient time for creative problem solving. One teacher commented that the curriculum "assists in the development of academic skills, but doesn't provide much support in the way of lifelong learning skills". Given school is where young people spend most of their time learning, and learning how to learn, it be hoped and assumed that the curriculum would facilitate the development of lifelong learning skills. This may be a contributing factor to graduates finding it difficult to attain employment as it is perhaps these lifelong learning skills that are among those deemed to be lacking by potential employers (Tonkin, 2019).

Approximately 12% of respondents indicated that the Science curriculum moderately supported skill development, or that it effectively developed a subset of the skills. The remaining 44% indicated that the Australian Science Curriculum effectively supported the development of a wide range of skills. Some of these teachers noted that, while there was a lot of content to cover, the curriculum itself is not too rigid and that there is flexibility in how it can be delivered. Some specific skills that were identified as being effectively developed by the curriculum were scientific literacy, deductive reasoning, communication, love of learning, technology, numeracy and literacy skills. One teacher noted that the 'Science Inquiry Skills' and 'Science as a Human Endeavour' strands of the Australian Curriculum helped to maintain a focus on skills as well as knowledge.

However, even those who responded positively raised some concerns, such as there are "too many skills in the Australian Curriculum" and that there is not the infrastructure or systemic capability required to effectively implement it. Several teachers indicated that regardless of provision for skill development within the Curriculum, it is ultimately up to the school and the teacher how it is implemented. Two comments are worth reading in full in this respect,

> It depends on how the syllabus document is interpreted within the classroom. There is scope for teachers to cover the curriculum developing all of the skills described above.[21] However, I believe that the Australian Curriculum can be adhered to with minimal development of the above skills. Good leadership within the school is essential in this regard.

> I think the Australian curriculum provides the opportunity to do all of these things, but I think at the end of the day it comes down to how it is interpreted and implemented in the school. For example, teachers in my school, and previous schools, have insisted students memorise significant chunks of the periodic table, rather than teaching students how to use technology or problem solving to navigate the periodic table. I think more could be done in the Australian curriculum to highlight how these skills could be integrated.

Such comments, compared with those on the previous page, reinforce the fact that perspectives on the overcrowding of the curriculum are very subjective. Likewise, there are wide-ranging and at times contradictory views on how effectively STEM skills can be developed by the Australian Science Curriculum. This adds weight to the notion that, ultimately, a curriculum document is just one factor that contributes to what students will learn in a classroom – what the teacher does with the curriculum is highly variable and thus more telling. Unfortunately, details on exactly how teachers implement the curriculum were beyond the scope of this study.

Mathematics. Fewer comments were made regarding the support provided by the Australian Mathematics Curriculum for the development of STEM skills. A few teachers indicated that it provided limited support. For example, one wrote in terms of the Year 7 Mathematics Curriculum and indicated that there were limited opportunities to develop skills such as programming and technology design because "you really need to be able to make big projects capable of arching into these different fields effectively". There is undoubtedly some truth in that comment, and it is difficult to design such

[21] Skills from the framework generated in Chapter 5 Part 1a were provided in list form for teacher reference as examples of STEM skills when responding to this question.

large projects without time for collaboration between staff and some creativity with regards to how content is to be delivered. The majority of respondents said that the curriculum provided moderate support for the development of these skills, with some caveats. As was the case for Science, several teachers commented on lack of time, the cramming in of too much content, and that it was dependent on the teacher's interpretation and evaluation of the curriculum.

Technologies. Comments pertaining to the Technologies were split into Design Technologies and Digital Technologies. Seven comments were made regarding the Design Technology curriculum and they were generally positive. One teacher suggested that the Technologies curriculum could be improved as they feel it is easy for students to just use programs as tools rather than developing a skill set. A few teachers indicated that they found it to be better than other curricula they had implemented previously, that it is flexible, enabling them to interpret it in "a diverse, innovative and expansive manner" and that the Australian Design Technology Curriculum provides direction to reflect and think about how learning occurs, particularly regarding the design process.

Only five comments were made regarding the Digital Technology curriculum and none provided much detail to justify their comments which ranged from "to a small extent – never enough time to really explore" through to "very much so". These comments further underscore the variety of perspectives on the curriculum itself.

Integrated STEM electives based on Australian Curriculum learning areas. The last set of responses were from five teachers who responded with respect to an integrated STEM subject, with all of them indicating at least moderate support from the curriculum. One teacher indicated that the curriculum provides little focus on creative design skills, critical evaluation or analysis for complex problem solving. Another indicated that they tried to make strong connections to the broader Australian Curriculum, especially general capabilities and skills, when teaching. However, that respondent did not indicate which skills they felt they were specifically able to effectively develop.

Overall. The fact that responses ranged from "not at all" to "a great deal", even when discussing the same subject area, highlights the subjectivity that is omnipresent in teachers' interpretation of curriculum documents. From teachers' comments, it seems that teachers who value skill development are likely to incorporate it within their teaching. Conversely, those who value knowledge acquisition focus more on the description of content to be covered rather than thinking about skills that could be developed during the learning process. It was interesting that only one teacher, who was teaching an integrated STEM subject that was therefore not directly based on the Australian Curriculum, referred explicitly to the general capabilities. No one referred to the cross-curriculum priorities of the Australian Curriculum. The latter is less problematic given the relative lack of attention to skills within them. However, the general capabilities have a significant overlap with the STEM skills, as discussed in Part 2a of this chapter. Most teachers indicated at least moderate familiarity with the general capabilities. However, no one made an explicit connection between the general capabilities and the development of STEM skills. Some respondents may take the fact that they know that the general capabilities exist to mean that they are moderately familiar with them. This suggests that teachers may know what the general capabilities are but that they do not necessarily invest time in covering them within their own learning area. Given the lack of support provided for many general capabilities within Science and Mathematics in particular, this is arguably justifiable.

Summary of Chapter 6

In Section 4 of the survey it was shown that teachers, on the whole, were more familiar with some aspects of the Australian Curriculum, such as content descriptions and achievement standards, than they were with the rationale, aims and so on. While this is, perhaps, to be expected, it is problematic in that some teachers are implementing the curriculum with a lack of awareness of the rationale and aims that underpin the curriculum. Furthermore, skills that take time to develop and need to be practised on a regular basis, such as disciplinary literacies and intrapersonal skills, are often only highlighted in the earlier components of the curriculum, not within the sections with which teachers were found to be more familiar. The nature of the content descriptions can also influence the focus in a classroom to be predominantly about acquiring knowledge or developing skills within a range of contexts. The Mathematics and Science curriculum content descriptions and elaborations are very knowledge-based. While there are strong overlaps with the STEM knowledge outlined by Carnevale et al. (2011), there is little focus on STEM skills and thus, unless valued by the teacher, they may not be given due consideration during planning. The Technologies place a much more consistent focus on STEM throughout the components of its curriculum and highlight many of the skills identified in Chapter 5 Part 1a, as well as some others which would fit within the domains of the framework. The content descriptions with which teachers tend to be most familiar, are very skills focused. The range of contexts provided as examples also demonstrate that the Technologies could be used as the basis for an integrated STEM course, if desired, as meaningful links to Mathematics and Science can be made in addition to the pre-existing grounding of the learning area in Technology and Engineering. It is unfortunate that this learning area is not compulsory until the end of Year 10 (elective from Year 9) as all students could experience beneficial skill development via participation in this learning area for as long as possible.

Teachers who were implementing the Australian Curriculum at the time of the survey were also invited to make comments regarding how supportive the Australian Curriculum was for the development of the skills in the framework constructed in Chapter 5 Part 1a. Most respondents indicated that there was relatively little focus on skills specifically within the curriculum, though some highlighted the fact that there is some flexibility in how the curriculum is implemented. Teachers who see how to meaningfully make links between their learning area and the general capabilities are more likely to cultivate a range of skills in their students because, as was shown in Part 2a of this chapter, the general capabilities themselves encompass a wide range of STEM skills.

Chapter 7 presents the results and discussion for the third and final research question. It outlines the skills assessed by PISA and TIMSS as described within the OECD and IEA's framework documents and compares what these tests assess to the STEM skills outlined in the framework of Part 1a in Chapter 5.

Chapter 7 – Results and Discussion for Research Question 3 – To what extent do PISA and TIMSS assess STEM skills?

Introduction

Assessment framework documents for each test were examined from the first round of testing up to the 2015 iteration of both tests. For PISA, the mathematical literacy and scientific literacy components of every test were examined, along with the problem solving component in the years in which it was assessed. TIMSS only assesses mathematics and science and so both components were examined from each iteration. The skills identified from both were compared with the domains of STEM skills identified from the literature (literacy, disciplinary, higher order thinking, interpersonal and intrapersonal) to determine the suitability of PISA and TIMSS for inferring Australian students' achievement when it comes to STEM skills.

Please note that results and discussion are presented together throughout this chapter.

PISA

Mathematics

Mathematics was the major domain in 2003 and 2012 and these are the years in which the most significant changes to the framework are evident. Many sample items are interspersed throughout the mathematics section of the framework document to highlight how particular concepts, contexts and processes are assessed. What follows is a brief overview of how PISA's assessment of mathematical literacy has developed over the first six rounds of testing. This is followed by a focus on the competencies PISA assesses as these are the aspects of PISA that are skill-based.

Evolving definitions of mathematical literacy. Three different versions of a definition for mathematical literacy have been used since PISA was first completed by students in 2000 through to 2015. Apart from some reordering of words, the definition for 2000 is essentially the same as that used in 2003-2009. In 2012 a richer definition was provided, which articulates more clearly what is meant by mathematical literacy. Figure 44 shows the relationship between the definitions, what they have in common, and what was added from 2012 onwards.

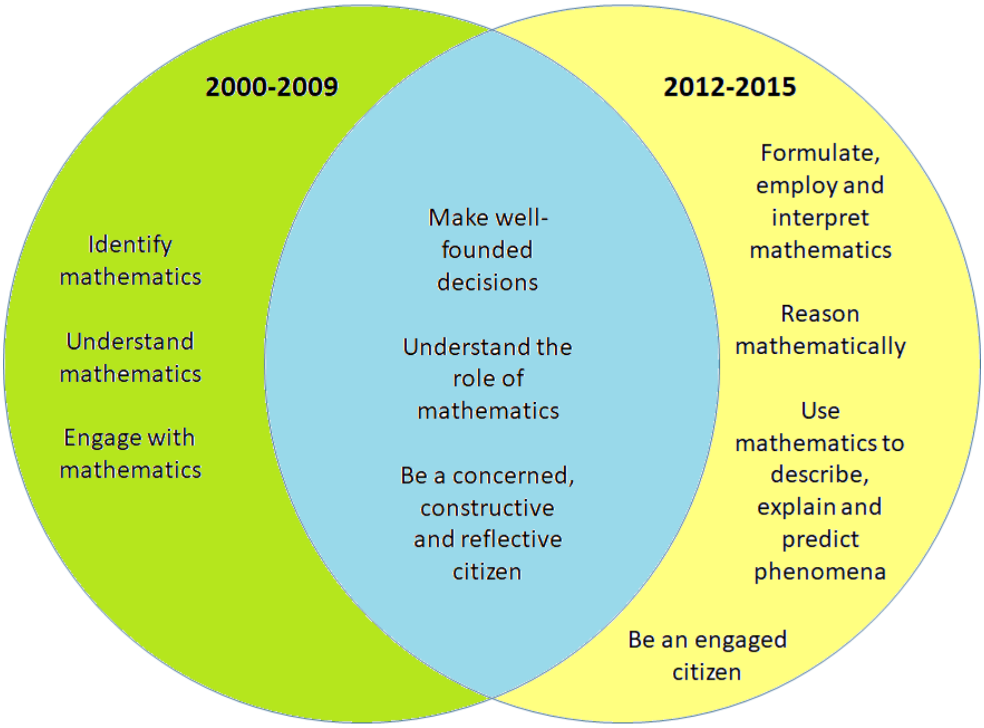

Figure 44 – Evolution of mathematical literacy in PISA (OECD, 2000, p. 50; 2003a, p. 24; 2006, p. 72; 2009, p. 84; 2012, p. 25; 2017, p. 67)

The central blue section, common to all definitions, is key to mathematical literacy in terms of its usefulness in everyday life, regardless of career choice. The more simplistic components outlined in the earlier definition (green circle) have been enriched in the latter definitions (yellow circle) which indicate a much higher level of mathematical knowledge and skills. PISA is designed to assess mathematical literacy and so the OECD's evolving definitions were considered, alongside other sources, when defining mathematical literacy in Chapter 5 Part 1a. The definition used there was that mathematical literacy was the "Ability to utilise mathematics to solve problems and make decisions within the context of private, occupational and social life and as a reflective citizen" (Table 15). While those aspects are present within the OECD's definitions of mathematical literacy, as shown in Figure 44, the latter places a stronger focus on the disciplinary knowledge and skills underpinning mathematical literacy. Within the OECD's more recent definitions, (yellow circle), there are also some examples of higher order thinking skills such as reasoning.

Organisation of the Mathematics domain. The domain of mathematics has been centred on three aspects in each iteration of the test (OECD, 2017, p. 68):

- context – personal, societal, occupational, scientific;
- content – quantity, uncertainty and data, change and relationships, space and shape; and
- processes (termed competencies in 2006-2009) – formulate, employ, interpret/evaluate.

However, of greater interest from a skills perspective are the capabilities assessed by PISA (OECD, 2017):

- communication – decoding of questions as well as the presentation of a solution, which sometimes requires an accompanying explanation or justification;
- representation – requires students to interpret mathematical ideas through a variety of different media, which they may also use to present their work, such as diagrams, equations, formulae, graphs, tables and figures;
- devising strategies – focused upon selecting a strategy used to solve a problem;
- mathematisation – the process through which a real-world problem is transformed into a purely mathematical model of the original problem so that it can be solved;
- reasoning and argument – being able to provide mathematical reasoning, make inferences, draw conclusions and justify them
- using symbolic, formal and technical language and operations –mathematically-specific communication, being able to express ideas using appropriate mathematical language; and
- using mathematical tools – being able to use tools typically required to solve mathematical problems, such as rulers, protractors, calculators, graphing software and so on. This requires students to understand their purpose mathematically and that these tools, especially graphing software, can add depth to communication.

Within this list of competencies, skills inherent to the discipline of mathematics are most clear within mathematisation and using mathematical tools. Examples of the use of higher order thinking skills are present within devising strategies as well as reasoning and argument. The remaining competencies are all related to communication. However, the only form of communication required is within a written mathematical context, so it is arguably more disciplinary than interpersonal in nature (in terms of the five domains of STEM skills from Chapter 5 Part 1a).

Assessment of mathematical literacy. In 2000, mathematical competency was divided into three clusters based upon “the type of thinking skill needed: i) reproduction, definitions and computations; ii) connections and integration for problem solving; and iii) mathematisation, mathematical thinking, generalisation and insight” (OECD, 2000, p. 51-52). These clusters represent three different levels at which students can demonstrate competency. Depending on the content of the question, it is noted by the OECD that students may have to move between these clusters to fully answer the question (OECD, 2000).

In 2012-2015 these competencies were re-expressed, with results being reported according to the following three processes (OECD, 2012, p. 28):

- *formulating* situations mathematically;
- *employing* mathematical concepts, facts, procedures, and reasoning; and
- *interpreting*, applying and evaluating mathematical outcomes.

These processes were maintained in 2015 and have a direct link to the description of mathematical literacy in these years (see top of yellow section of Figure 44). Approximately 50% of the mathematics component of PISA is dedicated to employing, with formulating and interpreting accounting for approximately 25% each. Three types of response format are typically used in assessing mathematical literacy: open constructed-response, where students show working or may need to provide an explanation; closed constructed-response, where students provide a word or number as an answer; and selected-response, made up of simple and complex multiple choice questions. No information was provided regarding the relative weightings of the response types (OECD, 2017).

PISA results are typically reported against proficiency standards with the Level 6 (top performing) description, which has not changed since first used in 2003, below:

> At level 6 students can conceptualise, generalise and utilise information based on their investigations and modelling of complex problem situations. They can link different information sources and representations and flexibly translate among them. Students at this level are capable of advanced mathematical thinking and reasoning. These students can apply their insight and understandings along with a mastery of symbolic and formal mathematical operations and relationships to develop new approaches and strategies for attacking novel situations. Students at this level can formulate and precisely communicate their actions and reflections regarding their findings, interpretations, arguments and the appropriateness of these to the original situations (OECD, 2017, p. 79).

This proficiency description highlights some of the skills to be assessed, albeit in less detail than the seven competencies outlined previously. There is a very strong focus in the proficiency description on skills inherent to the discipline of mathematics as well as the use of higher order thinking within a mathematical context. No mention is made of applying mathematical knowledge and skills to decision making contexts facing society, which is a key part of mathematical literacy, which is what the OECD claims PISA is designed to assess (OECD, 2017). The competencies and proficiency descriptions indicate that there is little focus, if any, on the blue section of Figure 44 nor the ‘engaged citizen’ part of the yellow section. The focus is almost entirely upon formulating, employing and interpreting mathematics, reasoning mathematically and, to a limited extent, using mathematics to describe, explain and predict phenomena. Thus, it is argued that the mathematical component of PISA does not assess all aspects of its own definition of mathematical literacy, certainly not the components of its definition that are used as the basis of the argument for the importance of disciplinary literacies for all students (Bybee, 2016). Furthermore, this component of PISA at least cannot be said to assess a wide range of STEM skills. While a range of skills of the mathematical discipline, as well as some higher order thinking skills, are assessed, they are generally predicated on requisite disciplinary knowledge.

Science

The definition of scientific literacy, as being assessed by PISA, has also evolved over time, as have the competencies it seeks to assess. What follows is a brief overview of how PISA's assessment of scientific literacy has developed over the first six rounds of testing. This will be followed by a focus upon the competencies assessed within this component of PISA.

Evolving definitions of scientific literacy. Table 24 depicts the definitions provided for scientific literacy over time. The same definition was used in 2000 and 2003, an updated definition was utilised from 2006 to 2012, with a new definition being provided in 2015.

Table 24 – Definitions of scientific literacy in PISA (OECD, 2000, p. 76; 2003a, p. 133; 2006, p. 23; 2009, p. 128; 2012, p. 100; 2017, p. 22; 2018, p. 75)

2000 and 2003	2006, 2009 and 2012	2015
The capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity.	For the purposes of PISA, *scientific literacy* refers to an individual's: • Scientific knowledge and use of that knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues • Understanding of the characteristic features of science as a form of human knowledge and enquiry • Awareness of how science and technology shape our material, intellectual, and cultural environments • Willingness to engage in science-related issues and with the ideas of science, as a reflective citizen.	Scientific literacy is the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen. A scientifically literate person is willing to engage in reasoned discourse about science and technology, which requires the competencies to: • **Explain phenomena scientifically** – recognise, offer and evaluate explanations for a range of natural and technological phenomena • **Evaluate and design scientific enquiry** – describe and appraise scientific investigations and propose ways of addressing questions scientifically • **Interpret data and evidence scientifically** – analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions.

PISA 2006 was the first round of testing in which science was the major domain and, as a greater proportion of the test was focused upon science, the working definition of scientific literacy was expanded. The version used from 2006 to 2012 included some reference to the nature of science, the links between science and technology and being able to make decisions about scientific issues. There is quite a change evident between the definition used from 2006-2012 and that used in 2015.

They do have some aspects in common, such as being able to use scientific knowledge to explain phenomena, drawing evidence-based conclusions and being a reflective citizen. However, there is less of a focus on the nature of science and the relationship between science and technology with the focus shifting to scientific investigations and the evaluation of data, claims and arguments.

The most recent definition was used in developing a definition of scientific literacy for Chapter 5,

> ability to use scientific concepts and processes in explaining phenomena and interpreting data and evidence when making personal and collective decisions that affect issues such as those related to the environment, health and technology, as well as participation in civic and cultural affairs and economic productivity (NRC, 1996; OECD, 2017).

The early components of the 2015 column of Table 24 are present within the definition above. However, in the remaining components of the definition, whilst perhaps tending towards genuine scientific literacy more than was the case for mathematical literacy, still require a lot of assumed knowledge. For the first time, the OECD articulated three distinct types of scientific knowledge (OECD, 2017):

- content knowledge – knowledge of scientific facts and theories and so on;
- procedural knowledge – an understanding of how practical science is conducted, including awareness of how to reduce error and uncertainty, control variables and handle data; and
- epistemic knowledge – an understanding of how knowledge within science is built.

In this respect, the OECD is up front in acknowledging that they are assessing a lot of *knowledge*. The skills being assessed are less clear. It should also be noted that as one moves from left to right within Table 24 that there is an increase in the amount of knowledge required, indicating an ever increasing focus on knowledge.

Organisation of the science domain. The domain of science is organised around a range of aspects. In 2000 and 2003 there were three: contexts, knowledge and competency. Attitudes have been included as a fourth aspect since 2006. The competencies will again be the focus as it is the most aligned with skills. The competencies within science are bolded within Table 24 (explain phenomena scientifically; evaluate and design scientific inquiry; and interpret data and evidence scientifically). The OECD notes that "all of these competencies require knowledge" (OECD, 2017, p. 21) which strengthens the contention that the OECD's definition of scientific literacy is very reliant upon background knowledge.

The competency pertaining to explaining phenomena scientifically has evolved from a focus on recall and the ability to apply knowledge to a range of unfamiliar situations, through to using this information to generate models to explain concepts, justify hypotheses made by the student and to explain the impact of scientific knowledge to society. The second competency has focused predominantly on evaluation of science within an experimental context and has increased in rigour over time. It assesses the ability of students to: identify an investigable question; propose and evaluate various means of investigating a question; and the ability to evaluate variables, reliability and validity, objectivity, and generalise within a given investigation. The final competency has shifted from communicating a conclusion in 2000, to requiring greater interpretation of evidence over time. In 2015 this has been further expanded to include transforming data representations, identifying the assumptions being made when drawing a conclusion and the evaluation of scientific arguments (OECD, 2000, 2003a, 2006, 2009, 2012; 2017).

Focusing on 2015, as it is the most detailed description as well as most recent, one can identify a range of skills that PISA seeks to assess based on its competencies which overlap with the STEM skills identified in the literature that underpinned Chapter 5 Part 1a. The science domain is strongly dominated by skills specific to the discipline of science as well as higher order thinking skills.

Assessment of scientific literacy. Examination of the proportion of score points assigned to each of the competencies over the history of PISA indicates that over 40% of the scientific literacy component of PISA is typically dedicated to explaining scientific phenomena, which essentially tests students' content knowledge alone. Approximately 23% of the test is focused on investigating scientific issues while the remainder of the test is dedicated to the use of scientific evidence, the latter has generally increased in focus over time (Yip (2008); cited in Lau, 2009; OECD, 2003a; 2009, 2012, 2017).

In terms of the types of knowledge being assessed, 40% of the questions are dedicated essentially to knowledge alone, predominantly content knowledge, with procedural and epistemic knowledge being required to answer the remaining questions. Although knowledge is not intended to be the hurdle in such questions, the extent to which one can demonstrate skills if missing a piece of assumed knowledge is questionable. Additionally, students ideally need to be assessed only on their scientific knowledge and skills, not their level of reading literacy. However, some questions have a substantial amount of text for students to digest. Most frameworks note that a certain degree of reading literacy is also required in order to access the test, with a statement such as the following being provided:

> The need for students to read texts in order to understand and answer written questions on scientific literacy raises an issue of the level of reading literacy that is required. Stimulus

> material and questions use language that is as clear, simple and brief, and as syntactically simplified as possible while still conveying the appropriate meaning. The number of concepts introduced per paragraph is limited. Questions within the domain of science that assess reading or mathematical literacy are avoided (OECD, 2017, p. 43).

While efforts have been made to reduce the impact of students' reading literacy on the assessment of their scientific literacy, it does nevertheless remain a concern as it is impossible to completely tease the two apart. Ultimately, one can argue that the key thing being assessed within the science component of PISA is scientific knowledge. There are some links to scientific literacy, certainly more so than to mathematical literacy within the mathematics component. However, both are much better tests of knowledge than skills.

Problem solving

Problem solving was assessed in the 2003, 2012 and 2015 iterations of PISA, though in quite a different manner in each instance. Each of the framework documents note the central importance of problem solving. Yet each also acknowledges the difficulty expressed within the literature to comprehensively define what problem solving is or how it ought to be assessed, particularly within the context of a large-scale standardised test such as PISA (OECD, 2003a, 2012, 2017). The following section explains how the OECD's definition of problem solving has evolved over time, the different ways in which it has been assessed, and the key skills required to succeed in the problem-solving units of PISA.

Evolving definitions of problem solving. In 2003 PISA was a paper-based test and the focus was on students' cognitive abilities in the face of non-routine, cross disciplinary scenarios (OECD, 2003a). Problem solving was omitted from PISA 2006 and 2009 but reappeared in 2012 with some changes since its first inclusion in 2003. Advances in research pertaining to the assessment of problem solving as well as in the use of technology for computer-based assessment. The OECD (2017) thus judged that the time was right to assess problem solving again in 2012, this time in a computer-based manner. The aim was to avoid the necessity of domain-specific content knowledge as much as possible so that the cognitive processes required for problem solving were the focus of the assessment. The definition used in 2012 was similar, though the specific mention of the cross-curricular nature of problem solving was removed and a reference to the use of problem solving being used within everyday life was included (OECD, 2017).

PISA 2015 saw quite a dramatic change, with collaborative problem-solving being assessed for the first time. A lengthy rationale for its inclusion is provided, focused mainly on the importance of collaboration within the workforce where individuals need to be able to work within a team, manage conflict, arrive at a consensus and communicate. To include the collaborative aspect required a focus on determining how students manage and communicate within a group situation. Due to this shift in focus from individual to collaborative problem solving, the definition in 2015 was quite different from earlier iterations, with a shift to a focus on the collaborative skills rather than the cognitive skills required to solve a problem (OECD, 2017).

Evolution of the organisation of the domain. In assessing problem solving skills in 2003 there was a focus upon the following components: problem types; the context of the problem; the disciplines involved; the problem solving processes required for a task; and reasoning skills. The problem solving processes assessed were: understanding; characterising; representing; solving; reflecting; and communication. Three problem types were included:

- decision-making problems – require students to identify constraints, alternatives, evaluate available options, justify their selection and communicate it clearly
- systems analysis and design problems – students need to understand relationships between variables, identify key features, ensure goals are achieved, evaluate, justify and communicate their solution; and
- trouble shooting problems – require students to understand the logic of the key underlying mechanism (e.g. of a physical system or procedure), diagnose the issue and propose a solution, and often require students to interpret information from multiple forms of representation and/or provide a representation of their own.

Analytic, quantitative, analogical and combinatorial reasoning skills were required to solve each problem type. The interpersonal skills often required to solve problems in real life were not assessed in any way as students worked individually. (OECD, 2003a).

The problem solving processes of 2012 differed a little from the processes of 2003. In 2012 they included: exploring and understanding; representing and formulating; planning and executing; and monitoring and reflecting. A wider range of reasoning skills were also required for the problem solving questions, including deductive, inductive, correlational and multidimensional reasoning (OECD, 2012).

The organisation of the domain in 2015 was significantly different to prior iterations. The interactions between problem solving skills (called processes in 2012) and the collaborative problem solving competencies is shown in Table 25.

Table 25 – Matrix of collaborative problem solving skills for PISA 2015 (OECD, 2017, p. 137)

	Understanding and maintaining a shared understanding	**Taking appropriate action to solve the problem**	**Establishing and maintaining team organisation**
Exploring and understanding	Discovering perspectives and abilities of team members	Discovering the type of collaborative interaction to solve the problem, along with goals	Understanding roles to solve the problem
Representing and formulating	Building a shared representation and negotiating the meaning of the problem (common ground)	Identifying and describing tasks to be completed	Describing roles and team organisation (communication protocol/rules of engagement)
Planning and executing	Communicating with team members about the actions to be/being performed	Enacting plans	Following rules of engagement (e.g. prompting other team members to perform their tasks)
Monitoring and reflecting	Monitoring and repairing the shared understanding	Monitoring results of actions and evaluating success in solving the problem	Monitoring, providing feedback and adapting the team organisation and roles

There were three different types of tasks used within PISA's 2015 collaborative problem solving tasks (OECD, 2017):

- consensus building – the group needs to arrive at a decision
- jigsaw problems – in which each group member has different information and/or skills and thus the problem cannot be solved by one member alone; and
- negotiations – where members have different information and different goals and need to negotiate to reach the best outcome for everyone.

It is clear from Table 25, as well as the three tasks types described above, that the problem solving and reasoning type skills required in 2003 and 2012 have been almost completely overshadowed by collaborative skills in 2015. Very little can be achieved by the individual taking the test without engagement with the computer agents who represent the other members of the group.

Assessing problem solving. In the 2003 paper-based test a mix of multiple choice, closed constructed-response and open constructed-response were used. The latter being used for about 50% of the test and the remaining 50% being split between the other two formats. It was indicated that rubrics that identified different levels of student achievement across the following criteria would be used: “understanding the information given; identifying or characterising the critical features and their interrelationships; constructing or applying a representation of the problem; solving the problem; checking, evaluating or justifying aspects of the problem; communicating the problem solution” (OECD, 2003a, p. 179). The assessment is very clearly focused on different cognitive processes associated with solving a problem.

The use of computer-delivered assessment in 2012 changed the nature of assessment substantially. It was noted that “Only foundational ICT skills are assumed in the assessment, such as keyboard use, using a mouse or touchpad, clicking radio buttons, drag and drop, scrolling, and use of pull-down menus and hyperlinks” (OECD, 2012, p. 127). While an attempt has been made to separate problem solving skills from the ICT skills required to complete the task, it is impossible to completely rule out the impact of differing ICT skills on the completion of the task. Approximately a third of items were multiple-choice or involved a drop down menu etc.; roughly half of the questions were closed constructed-response with the remaining 20% or so requiring students to type a response. An example of the impact of ICT skill level on the results is that students who were able to type faster would develop a time advantage, allowing them more time to solve problems than their peers who could not touch type. A proficiency scale was not included, but it was suggested that high performing students would be able to: plan and execute solutions; think a number of steps ahead; meet multiple constraints; use complex reasoning skills; monitor progress; modify plans; make links between pieces of information; interact with problems to uncover undisclosed information (OECD, 2012). Whilst quite different in nature to the processes being assessed in 2003, these remain very focused on the skills required to solve a problem.

When PISA 2015 was being designed there were no established methods regarding how to run a large-scale, international assessment of collaborative problem solving at the individual level. It was noted by the OECD that minimal comparison to the results from 2012 can be meaningfully made, as individuals’ cognitive problem solving skills were not being directly assessed in 2015, rather how problem solving played out in a collaborative environment. Actions, communications, products and response times were all documented while the student completed the test and each aspect was used in measuring their performance. As it was logistically impossible to have students collaborate with other students in a large-scale standardised format, conversational agents were used within the collaborative problem solving domain of PISA. These agents had a range of skills and abilities and provided “input in much the same manner as fellow students would do” (OECD, 2017, p. 145). However, to ensure that students completed enough tasks to assess their ability, "rescue" agents could redirect the course of action if progress was not being made. The OECD (2017) argued that this form of testing allowed the assessment of skills in a controlled setting whilst not directly testing a student's ability to work with other students. However, the nature of the agents' comments was questionable in terms of their realistic representation of fellow students. Furthermore, face-to-face interactions are very different from those conducted online with real humans, let alone virtual agents, so a range of the interpersonal skills vital for collaborative problem solving are not able to be assessed.

Herborn, Stadler, Mustafic, and Greiff (2018) investigated the effect of computer agents by obtaining the original PISA 2015 tasks. They used the original interface and the same predefined set of responses from which the test taker could select. While they found no significance regarding the *type* of collaboration, Herborn et al. (2018) found students performed a *wider variety* of actions when collaborating with a human. This begs the question of the validity of assessing collaboration via interaction with computer agents as the situation is significantly different from working with people, particularly in terms of the interpersonal skills required.

A four-level proficiency scale is provided for collaborative problem solving, with the description of the highest level being:

> At Level 4, students can successfully carry out complicated problem-solving tasks with high collaboration complexity. They are able to solve problems situated in complex problem spaces with multiple constraints, keeping relevant background information in mind. These students maintain an awareness of group dynamics and take actions to ensure that team members act in accordance with their agreed-upon roles. At the same time, they are able to monitor progress towards a solution to the given problem and identify obstacles or gaps to be bridged. Level 4 students take initiative and perform actions or make requestions to overcome obstacles and resolve disagreements and conflicts. They can balance the collaboration and problem-solving aspects of a presented task, identify efficient pathways to a problem solution, and take actions to solve the presented problem (OECD, 2017, p. 150).

The proficiency scale makes a few more allusions to the actual solving of problems than is present in the matrix shown in Table 25. However, skills associated with collaborating with the online agents dominate. Given the questionable reliability of assessing collaboration, this again raises the question of why such a focus is placed on the collaborative aspect rather than what can be more reliably assessed, an individual's problem solving ability, as was done in 2003 and 2012.

The problem solving domain, when included, provides the opportunity to investigate not just problem solving skills, but also a range of thinking skills associated with solving problems. Interestingly, ACER's report on Australia's PISA 2015 results does not comment on the collaborative problem solving domain at all (S. Thomson et al., 2017), nor did the 2012 report mention the problem solving domain or comment on Australia's performance (S. Thomson et al., 2013). In contrast to this, Australia's performance in the problem solving domain was a chapter of the ACER report on PISA 2003 (S. Thomson et al., 2004). Given the variety of skills being assessed by the problem solving component, it seems rather odd that it has been overlooked in 2012 and 2015. In 2003 it was thought that the problem solving domain would not be used again (S. Thomson et al., 2004) and yet it was analysed. By 2012 the addition of a collaborative component for 2015 was already being foreshadowed (S. Thomson et al., 2013), and yet no time was given to a consideration of what Australian students' results in problem solving might indicate. Considering the skills assessed within this domain, it would appear to be just as beneficial, if not more so, in providing insight into how Australian students fare on the world stage in terms of their skills.

PISA Summation

Significant questions remain about the extent to which PISA truly assesses disciplinary *literacy* in its fullest form, let alone the validity of using PISA to compare Australian students' STEM skills with those of students from other nations. While disciplinary knowledge is obviously a vital component of disciplinary literacy, they are not one and the same. The OECD's own definitions of mathematical and scientific literacy reflect that disciplinary literacies involve the ability to use knowledge and skills from the discipline to make decisions in a real-life context. While some of PISA's questions may attempt to model a real-world scenario, students are still ultimately sitting a test, they are not truly being required to solve a problem they may face as citizens. The context remains a test, not a real-life situation with access to the internet or other people when making a decision as would be possible in real-life (Sjoberg, 2012). Details from the assessment framework indicate that all aspects of the OECD's definition of mathematical literacy, and to a lesser extent scientific literacy, are *not* assessed, let alone a broad enough range of skills to be of use in making any judgement about students' STEM skills. Furthermore, technological and engineering literacy and/or skills are not mentioned.

The fact that a high level of general literacy is required to understand the questions and that, to an extent, ICT skills are also being assessed with the movement of the test online, further muddies the waters. If a student performs poorly it is almost impossible to determine why. Were they unable to access the question due to low reading literacy? Are they unfamiliar with taking tests online? Do they lack experience in touch typing? Did they not have the requisite background knowledge required for some questions? Were they lacking the higher order thinking skills to take their knowledge and use it to solve a problem? The list goes on. PISA assesses mathematical and scientific *knowledge* as well as a range of higher order thinking skills far more effectively than it assesses either disciplinary *literacy*.

The problem solving components of 2003 and 2012 extended the assessment of skills to focus more predominantly on the processes associated with solving problems that were not based within one discipline. Given the centrality of problem solving to STEM, it is somewhat odd that the problem solving domain is not analysed by ACER and that Australian students' achievement in mathematics and science, not problem solving, is reported upon in relation to how they are performing in STEM. As shown in Chapter 5 Part 1b, teachers placed a strong focus on problem solving and barely mentioned mathematical or scientific literacy. What the collaborative problem solving component of 2015 truly assesses is questionable, little mention is made of how students' *problem solving* ability was measured, the focus is much more on their *collaborative* ability. However, it is a form of collaboration that is not at all representative of real life. It must be concluded, therefore, that PISA is not an appropriate metric for determining the STEM skills of Australian students.

TIMSS

The framework documents provide information regarding the objectives and nature of the test at the Year 4 and Year 8 levels for mathematics and science. Across both disciplines, students' abilities are assessed in two domains: content and cognitive. The content domain is designed to reflect the curricula of the participating nations and is updated regularly to reflect any major curriculum changes by participating nations. The cognitive domain of the most recent iterations are comprised of knowing, applying and reasoning. Earlier iterations had some additional categories. The cognitive domain is the area of focus here as it skill rather than knowledge dependent (IEA, 2016).

Mathematics

At the start of the chapter detailing the 2015 mathematics framework it is noted that "learning mathematics improves problem-solving skills, and working through problems can teach persistence and perseverance" (Gronmo et al., 2013, p. 11), acknowledging the intrapersonal skills that may be developed through a study of mathematics. However, it makes no mention of if or how those skills are be assessed. Table 26 shows the components of the cognitive domain of the Year 8[22] Mathematics test from 1995 through to 2015. The proportion of the test dedicated to each aspect is stated in brackets. Note that this information was unavailable in the case of the 1995 test.

[22] The Year 4 TIMSS is not being studied here as the focus of the thesis is on Years 7-10.

Table 26 – Evolution of the cognitive dimension of the TIMSS Eighth Grade Mathematics test (Gronmo et al., 2013; International Association for the Evaluation of Educational Achievement, 1995, 1999; Mullis et al., 2005; Mullis, Martin, Ruddock, O'Sullivan, & Preuschoff, 2009; Mullis et al., 2003)

<table>
<tr><th>1995</th><th>1999</th><th>2003</th><th>2007</th><th>2011</th><th>2015</th></tr>
<tr><td>Knowing</td><td>Knowing (19%)</td><td>Knowing facts and procedures (20%)
• Recall
• Recognise/identify
• Compute
• Use tools</td><td>Knowing (40%)
• Recall
• Recognise
• Compute
• Retrieve
• Measure
• Classify/order</td><td>Knowing (35%)
• Recall
• Recognise
• Compute
• Retrieve
• Measure
• Classify/order</td><td>Knowing (35%)
• Recall
• Recognise
• Classify/order
• Compute
• Retrieve
• Measure</td></tr>
<tr><td>Performing routine procedures</td><td>Using routine procedures (23%)</td><td>Using concepts (20%)
• Know
• Classify
• Represent
• Formulate
• Distinguish</td><td>Applying (40%)
• Select
• Represent
• Model
• Implement
• Solve routine problems</td><td>Applying (40%)
• Select
• Represent
• Model
• Implement
• Solve routine problems</td><td>Applying (40%)
• Determine
• Represent/model
• implement</td></tr>
<tr><td>Using complex procedures</td><td>Using complex procedures (24%)</td><td>Solving routine problems (40%)
• Select
• Model
• Interpret
• Apply
• Verify/check</td><td>Reasoning (20%)
• Analyse
• Generalise
• Synthesise/integrate
• Justify
• Solve non-routine problems</td><td>Reasoning (25%)
• Analyse
• Generalise/specialise
• Integrate/synthesise
• Justify
• Solve non-routine problems</td><td>Reasoning (25%)
• Analyse
• Integrate/synthesise
• Evaluate
• Draw conclusions
• Generalise
• Justify</td></tr>
<tr><td rowspan="2">Solving problems</td><td>Investigating and solving problems (31%)</td><td rowspan="2">Reasoning (20%)
• Hypothesise/conjecture/predict
• Analyse
• Evaluate
• Generalise
• Connect
• Synthesise/integrate
• Solve non-routine problems
• Justify/prove</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td></tr>
<tr><td>Communicating and reasoning (2%)</td></tr>
</table>

The first three iterations of TIMSS focused on similar cognitive processes with a redesign into three cognitive domains from 2007 onwards. Greater detail regarding what each domain consists of was provided from 2003 onwards, which helps in identifying the required skills. ‘Knowing’ has featured throughout and has varied in weighting from 20% to 40% of the cognitive domain. As the name suggests, the ‘knowing’ component requires students to know all the required concepts and essentially just be able to apply them. At most this requires some lower order thinking skills, but it seems to essentially be testing whether students know the content being tested.

The applying domain focuses on whether students can take this knowledge and use it to select, represent, model and implement strategies in the solving of routine problems. This solving of routine problems has increased substantially in weighting over time from 20% to a more consistent 40% in more recent iterations. This aspect of the cognitive domain relies more on skill than knowledge alone, but it is still only lower order thinking type skills.

Reasoning was introduced for the first time in 2003 and had a weighting of 20% that year. It has increased to 25% more recently. Key to this domain is the ability to analyse, generalise, synthesise, evaluate, draw and justify conclusions. Such skills fall into the higher order thinking class of skills. Unfortunately, this is the part of the domain with the lowest weighting and yet is the component that tests the skills of interest. The knowing and applying domains, which comprise 75% to 80% of the test are essentially what one would see in a knowledge-based test. TIMSS has a focus upon the curriculum and is typically seen as a way of comparing student progress at an equivalent point of learning in terms of what they *know*. The cognitive processes outlined in Table 26 indicate that the mathematics component of TIMSS is well-designed to achieve what it aims to do. However, it is not well-designed to assess students’ skills, as the whole test is predicated on comparing student knowledge of curriculum content between nations. The skills required are almost exclusively lower order thinking in nature, with a range of skills related to problem solving being of importance for a relatively small part of the test.

Science

Table 27 shows the development of the cognitive domain of science throughout TIMSS’ history with relative weightings for each aspect being provided except for 1995 as that data was unavailable.

Table 27 – Evolution of the cognitive dimension of the TIMSS Eighth Grade Science test (IEA, 1995; 1999; Jones et al., 2013; Mullis et al., 2005; Mullis et al., 2009; Mullis et al., 2003)

<table>
<tr><th>1995</th><th>1999</th><th>2003</th><th>2007</th><th>2011</th><th>2015</th></tr>
<tr><td>Understanding simple information</td><td>Understanding simple information (39%)</td><td>Factual knowledge (30%)
• Recall
• Define
• Describe
• Use tools and procedures</td><td>Knowing (30%)
• Recall/recognise
• Define
• Describe
• Illustrate with examples
• Using tools and procedures</td><td>Knowing (35%)
• Recall/recognise
• Define
• Describe
• Illustrate with examples
• Demonstrate knowledge of scientific instruments</td><td>Knowing (35%)
• Recall/recognise
• Describe
• Provide examples</td></tr>
<tr><td>Understanding complex information</td><td>Understanding complex information (31%)</td><td>Conceptual understanding (35%)
• Illustrate with examples
• Compare/contrast/classify
• Represent/model
• Relate
• Extract/apply information
• Find solutions
• Explain</td><td>Applying (35%)
• Compare/contrast/classify
• Use models
• Relate
• Interpret information
• Find solutions
• Explain</td><td>Applying (35%)
• Compare/contrast/classify
• Use models
• Relate
• Interpret information
• Find solutions
• Explain</td><td>Applying (35%)
• Compare/contrast/classify
• Relate
• Use models
• Interpret information
• Explain</td></tr>
<tr><td>Theorising, analysing and solving problems</td><td>Theorising, analysing and solving problems (19%)</td><td rowspan="2">Reasoning and analysis (35%)
• Analyse/interpret/solve problems
• Integrate/synthesise
• Hypothesise/predict
• Design/plan
• Collect/analyse/interpret data
• Draw conclusions
• Generalise
• Evaluate
• Justify</td><td rowspan="2">Reasoning (35%)
• Analyse/solve problems
• Integrate/synthesise
• Hypothesise/predict
• Design/plan
• Draw conclusions
• Generalise
• Evaluate
• Justify</td><td rowspan="2">Reasoning (30%)
• Analyse
• Integrate/synthesise
• Hypothesise/predict
• Design
• Draw conclusions
• Generalise
• Evaluate
• Justify</td><td rowspan="2">Reasoning (30%)
• Analyse
• Synthesise
• Formulate questions/hypothesise/predict
• Design investigations
• Evaluate
• Draw conclusions
• Generalise
• Justify</td></tr>
<tr><td>Using tools, routine procedures and processes</td><td>Using tools, routine procedures and science processes (7%)</td></tr>
<tr><td>Investigating the natural world</td><td>Investigating the natural world (4%)</td><td colspan="2">Will also assess students scientific inquiry skills including:
• Formulating questions and hypotheses
• Designing investigations
• Collecting and representing data
• Analysing and interpreting data
• Drawing conclusions and developing explanations</td><td>-</td><td>-</td></tr>
</table>

In early iterations of the test, the cognitive domain sought to assess quite different things in science than in mathematics. However, both now use the same three domains: knowing, applying and reasoning. The knowing and applying components for science are very similar to those used in mathematics (Table 26) and so again the focus in these domains is whether students know the content covered within the test and can they use some lower order thinking skills to demonstrate that they know how to apply that knowledge. Both domains have been weighted at 35% in recent iterations and so the reasoning component of the science test is weighted slightly more highly at 30% in science than in mathematics where it has been 25%. The skills within the reasoning domain are essentially the same as for mathematics with the addition of some science specific skills such as the formulation of questions/hypothesise/predict and the design of investigations. What is less clear, in both instances, is whether the reasoning domain also relies on knowledge that the students bring into the test with them, or if information is provided and they need to demonstrate their skills in the context of new information. If it is based on knowledge students bring in with them, students without the pre-requisite knowledge will never be able to fully demonstrate the full extent of their reasoning skills.

TIMSS Summation

The IEU makes it very clear that TIMSS is a measure of educational achievement, not a test of disciplinary literacy as the OECD suggests is the case for PISA, nor is it a test of skills. The IEU describe TIMSS as

> an international assessment of student achievement in mathematics and science at fourth and eighth grades … TIMSS assessments provide an authoritative account of how students in fourth and eighth grades perform in mathematics and science. Countries that participate in multiple cycles of TIMSS can monitor trends in student achievement while assessing changes that have occurred in curriculum, instruction, and other aspects of education that affect learning … the study collects detailed information about curriculum and curriculum implementation, together with empirical information about the contexts for schooling (IEA, 2020, para. 1-3)

As TIMSS examines national curricula and uses them to devise the assessments, TIMSS can be used to examine the effectiveness of *intranational* curricular reforms, such as the introduction of the Australian Curriculum. The IEU does not suggest that TIMSS is a measure of skills, and certainly not of STEM skills. Australia’s declining results are cause for concern in terms of what Australian students know and can do within mathematics and science compared with their international peers. This is possibly an indication that the Australian Curriculum (old and new) is not as rigorous as other nations. Results should *not* be used to argue that Australian students’ are falling behind their international peers in *skills*, and definitely not in STEM skills as defined in Chapter 5 Part 1a by any source, including Siekmann and Korbel (2016), as very few if any of what they call ‘technical skills’ are assessed.

The impact of standardised tests in the classroom

Before concluding the chapter, it is worth commenting on the effect of international tests such as PISA and TIMSS have on Australian teachers and their students. While the focus in Australia is more regularly placed on NAPLAN[23], there is a building argument against PISA and TIMSS on the basis that these types of standardised tests are having an adverse effect on students' education. Jenny Allum, Head of the Sydney Church of England Girls' Grammar School in Darlinghurst, wrote an article for the Sydney Morning Herald in which she discussed the effect of PISA and NAPLAN on schools. In it she wrote,

> The first goal of the Australian Education Act of 2013 is for Australia to be in the top five countries in the OECD ranking of countries in their Programme for International Student Assessment (PISA) study, intended to evaluate educational systems by measuring 15-year-old school pupils' scholastic performance on mathematics, science, and reading.
>
> I would not put this at the top of the list that describes the purposes of schooling. These narrow tests warp what happens in schools, in what is written into curriculum documentation and so on. I want us to regard creativity, divergent-thinking and innovation as also important, and to place as fundamental values such as encouraging young people to strive towards a just and compassionate society, and ensuring that our students know how to be good people, people who can live their lives with integrity and strength. I want our priorities for education to be broader than league tables of countries or schools (Allum, 2018).

Most people would presumably agree that what students are learning and the values they are developing are more important than where Australia ranks in international tests. However, it is the latter that makes the headlines. It has been argued that a focus on teaching to NAPLAN may be adversely effecting students' capability to perform well in tests such as PISA which are designed to be more complex (Singhal, 2018). Some even argue that aspects of NAPLAN, such as the persuasive writing written test, "subverts critical thinking" (Sowey, 2018, p. 13) as insufficient weight is given to the formulation of a coherent argument which engages critically with relevant issues.

While NAPLAN and PISA are very different tests, NAPLAN and TIMSS are similar in that they are based on determining students' mastery of curriculum content. However, the concept of 'teaching to' any of these tests is something that ought not to be encouraged. As Allum (2018) suggests, education is about far more than performance on standardised tests. Furthermore, a standardised test provides minimal insight into student achievement. Australian Education Union President Correna Haythorpe supports the notion that a teacher's assessment of students' capabilities is far more valuable than any standardised test, saying "A child's education cannot simply be

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[23] A test taken by all Australian students (unless parents/teachers apply for an exemption, e.g. for students with intellectual disabilities) in Years 3, 5, 7 and 9 which assesses literacy and numeracy. Results are recorded on the MySchool website which is described as "a resource for parents, educators and the community to find information about Australia's schools" (ACARA, 2019, para. 1). It includes information regarding schools' NAPLAN results, population data and financial information website which has led to NAPLAN results being used to rate schools rather than monitor the progress of students (Hickey, 2019).

encapsulated as a number in a spreadsheet – we need a much more holistic assessment process which is connected to the daily teaching that occurs in our schools" ("Teachers have lost faith in NAPLAN," 2019, p. 4). Furthermore, 88% of the Independent Education Union of Australia members surveyed in 2019 supported the use of "a formative assessment program that is created by and for teachers, that could be used when and where needed, as determined by the classroom teacher" (Watt, 2019, p. 17).

In terms of the assessment of STEM skills, there is little evidence to suggest that any standardised test, and certainly not PISA or TIMSS, are efficacious in determining students' STEM skill levels. There is, however, evidence that the focus put on these tests causes undue stress and anxiety to both students and teachers and that preparation for these tests diverts attention away from time better spent on more valuable learning opportunities. It must also be acknowledged that teachers are the experts when it comes to knowing their students and how they are progressing. Whatever information is gleaned from an analysis of the results of Australian students in PISA and TIMSS, it is important to acknowledge the broader issues associated with such forms of standardised testing.

Summary of Chapter 7

PISA is intended to measure students' disciplinary literacies as well as their ability to solve problems. Whilst focused on assessing mathematical and scientific literacy, PISA concentrates on an assessment of the skills needed to be literate. The OECD suggests that students will need a variety of mathematical and scientific skills, similar to the disciplinary skills identified in Chapter 5 Part 1a, as well as communication and higher order thinking skills such as the ability to evaluate, analyse and interpret information. While the 2015 inclusion of collaborative problem solving seeks to assess students' collaborative ability as well as their problem solving skills, the extent to which either are effectively assessed is questionable.

The IEA is quite open about the fact that TIMSS assesses students' proficiency in mathematical and scientific content that they ought to have learnt at school by the time they take the test. It is thus more open in its acknowledgement that TIMSS is a knowledge test.

Teachers can provide more insightful comments on their students' capabilities than any standardised test and such tests place a burden on students and teachers alike. It is worth considering, therefore, why so much time, money and energy is spent on developing and administering these tests when the accuracy and validity of them is disputed. This is not to say there is no benefit to be gained from the tests. Both can provide useful insights into some aspects of student learning and/or the curriculum being implemented. However, if data from PISA and/or TIMSS are being used to make an argument, a firm understanding of what each test does and does not assess is vital. Unfortunately, prominent organisations such as the Australian Industry Group (2013), ACOLA (Marginson et al.,

2013) and the OCS (2014a) frequently cite results in PISA and TIMSS as not just an indication that the average Australian student has less mathematics and science knowledge, but also that their skills are lacking. The skills to which they refer are generally discussed in the broader context of STEM skills, hence implying that PISA and TIMSS are valid means of assessment STEM skills. They are not. Neither test assesses a sufficient range of skills associated with STEM. At most, they can be used to compare Australian students' *knowledge* within mathematics and science to that of their international peers. It does not assess STEM as technology and engineering are missing. Furthermore, the skills that are assessed are typically lower order thinking, higher order thinking (particularly problem solving) and some skills specific to the disciplines of mathematics and science. PISA and TIMSS are not valid metrics with which to determine the STEM skill level of Australian high school students. Particularly not the broad range of skills identified as STEM skills by the literature and by teachers in Chapter 5. As it stands, neither test effectively assesses one domain, let alone aspects of all five domains that were identified.

The final chapter brings together the findings from the three results chapters by way of answering the three research questions and, ultimately, the overarching research question. Recommendations arising from the findings are made, limitations of the study are acknowledged, the significance of the findings stated, and future research directions are suggested.

Chapter 8 – Conclusions, Limitations and Recommendations

Introduction

The STEM workforce is a key focus of countries worldwide due to productivity and innovation within the STEM field being associated with a country's ability to be competitive on the world stage (Australian Industry Group, 2013; Marginson et al., 2013; OCS, 2014a). Australia, like many other nations, is experiencing a paradox in that STEM employers cannot find workers and yet STEM graduates cannot find jobs (Charette, 2013; Kramer et al., 2015). While there are a range of contributing factors to this issue, a key one is that STEM graduates lack the *skills* STEM employers desire (Australian Industry Group, 2015, 2018). The concept of a STEM pipeline is well established and is based upon the notion that people can drop out of the STEM pathway at a variety of points ranging from early childhood (in terms of interest) through to not choosing to study STEM subjects at secondary or tertiary levels, and moving out of a STEM career as a worker (Australian Academy of Science, 2019; van den Hurk, Meelissen, & van Langen, 2019). The last compulsory years of STEM education within Australia are Year 7-10, and so this was chosen as the focus age-group for this study. It was established in Chapter 3 that one of the biggest issues facing school leavers and graduates obtaining a job is lack of the required skills (Australian Industry Group, 2015, 2017, 2018; Marginson et al., 2013; Scutt, 2018; Tonkin, 2019). Therefore, this study sought to determine how Australian Year 7-10 teachers are to develop and assess the STEM skills their students will require to succeed in the workforce of today and tomorrow.

In order to address this question, three smaller research questions, two with their own sub-questions, were asked and have been the focus of the previous three chapters. What follows is a brief summation and discussion of the findings of these smaller research questions and how, together, they can be used to address the broader question. Recommendations that arose from the research, the significance of the findings, a discussion of the limitations of the study, and avenues for further research are also presented.

Key Findings and Recommendations

Research Question 1 – What are STEM skills?

- *Research Question 1a – What are STEM skills according to the literature?*
- *Research Question 1b – What are STEM skills according to Australian STEM teachers?*
- *Research Question 1c – How do the perspectives on STEM skills from the literature and Australian STEM teachers compare?*

Despite a strong focus on STEM skills in the traditional literature as well as governmental and industry reports, the skills meant by this phrase are not clear. The lack of clarity around what these skills are, and the different interpretations that are likely to arise in the absence of a clear definition, makes it difficult for students and teachers to know which skills to focus upon developing.

The best examples of lists of specific skills came not from the conventional literature, but from governmental and industry reports, and pertained to skills desired by employers in their employees. As the focus of this thesis is on Year 7-10, some of these skills were irrelevant within a school context or needed to be pared back. However, given a chief aim of education is to prepare the next generation of workers, it is reasonable to take skills desired by employers and scale them back to a framework of skills suitable for development within high school. Four reports were consulted in the development of this framework, each with its own focus and intent:

- Carnevale et al. (2011) used data from the O*NET database to determine the competencies that were found within STEM occupations across different industries.
- Aring (2012) focused on general employability skills but was deemed relevant for this study due to the difficulties experienced by graduates in obtain employment.
- Prinsley and Baranyai (2015) reported on the results of a survey conducted by DAE (2014) which was completed by Australian employers across different industries about the performance of STEM versus non-STEM graduates against a list of skills that was principally derived from the work of Carnevale et al. (2011) and Aring (2012).
- Finally, as two-thirds of the STEM jobs in Australia lie within the VET sector, a report by Siekmann and Korbel (2016) from the Australian National Centre for Vocational Education Research was consulted. It was based upon the work of Carnevale et al. (2011) and Prinsley and Baranyai (2015) and argued for the use of more specific terms other than the broad and ill-defined 'STEM skills.' For example, the use of the phrase 'technical skills' when those technical skills specific to STEM disciplines are meant.

Examination of these documents led to the proposal of five domains of STEM skills that could be developed within schools: literacy, disciplinary, higher order thinking, interpersonal and intrapersonal. Some examples of skills within each of these domains were outlined in Chapter 5 Part 1a, but they are by no means an exhaustive list. The conventional literature has started to become a little more explicit about the skills encompassed by 'STEM skills' of late (Achat-Mendes et al., 2019; Aris & Orcos, 2019; Cheng, 2019). However, the conventional literature remains nowhere near as articulate regarding the full range of skills needed for the STEM workforce as the reports consulted (above) and was therefore used as support for, rather than the chief source of, the skills ultimately chosen. It must be noted that the framework generated in Chapter 5 Part 1a is quite broad in nature and that there are people, such as Siekmann and Korbel (2016), who mean a much more specific group of skills by the phrase, such as only the technical skills that are specific to STEM disciplines. Therefore, it is prudent to explain what is meant by the term 'STEM skills' whenever it is used.

Research Question 1b sought to determine what Australian Year 7-10 STEM teachers think STEM skills are, and how this compares with the literature examined in answer to Research Question 1a (conventional as well as governmental and industry reports). The five skills most frequently identified by teachers were: problem solving, collaboration, creativity, critical thinking and communication. Each of these were identified within the literature. However, it is important to note that these five skills are drawn from only two domains drawn from the literature: higher order thinking and interpersonal skills. The most common teacher responses were best identified as higher order thinking. Whilst this is a domain that is by no means unique to STEM, the second most common response were disciplinary skills which, akin to what Siekmann and Korbel (2016) call technical skills, are specific to STEM disciplines.

Teachers made minimal mention of anything to do with literacy, and even less in terms of specific disciplinary literacies or STEM literacy. This was also the case in terms of the literature consulted in Chapter 5 Part 1a (with the exception of Aring (2012)). However, the decision was made to include the literacy domain in the framework because a key goal of STEM education outlined within the broader literature as discussed in Chapter 2 is to increase STEM literacy. There is a strong argument that STEM literacy is beneficial, if not essential, for all students as the world becomes increasingly technical (Bybee, 2016; Holmlund et al., 2018; NRC, 1996; OCS, 2013a; Timms et al., 2018; Zollman, 2012). Literacy is a key focus of the Australian Curriculum, as indicated by the inclusion of literacy as a general capability, the description of which indicates the need to develop disciplinary literacies within the learning areas. (ACARA, 2013f). A key focus of PISA is the assessment of mathematical and scientific literacies used to make cross-country comparisons in terms of STEM (OCS, 2014a; Marginson et al., 2013), regardless of how valid and reliable PISA is for that purpose. It is interesting therefore that teachers did not strongly identify literacy as a STEM skill.

Before moving on, it is worth comparing the skills identified in Chapter 5 with the skills outlined within the National STEM School Education Strategy and the various state/territory STEM strategies, as presented in Table 2. The capabilities identified within the National strategy are: creative thinking; critical analysis; problem solving; mathematical, scientific and technological literacy; and STEM discipline skills. Thus, it taps into the literacy, disciplinary and higher order thinking domains of the framework and has overlaps with the skills identified by teachers. However, no reference is made in the strategy to interpersonal or intrapersonal skills. Other jurisdictions have their own list of capabilities which differ wildly with creative thinking, critical analysis and problem solving being the exceptions as they are listed skills in seven of the eight strategic documents. In addition to capabilities, a list of dispositions is included within many state and territory strategies. While dispositions have some overlap with the intrapersonal domain and the attributes identified by teachers, only five dispositions in total were identified across the strategies: aspirations; curiosity; growth mind-set;

interest; and resilience. Only the National, NSW, NT and TAS strategies listed any dispositions and each aspiration was only included in one strategic document, indicating no consistency in dispositions across the documents. The fact that each jurisdiction focuses on its own subset of capabilities and dispositions tends to suggest that they may be working towards the development of different capabilities and dispositions depending on their jurisdiction. This hardly seems a practical way of increasing more Australian students' STEM skills.

What are STEM skills? There is some correlation between what the literature suggests are STEM skills and what teachers identify as STEM skills. Both placed a large focus on higher order thinking and disciplinary skills. The literature used in Chapter 5 Part 1a and the teachers surveyed in Part 1b put little emphasis on the importance of disciplinary literacies. However, this is not representative of the literature more broadly, where STEM literacy is used as an argument for the importance of STEM education for all students. Teachers responded with a broader range of examples of skills, however, they each sat within one of the domains that emerged from the literature or were skills which underpin them (such as lower order thinking skills). Overall, Australian Year 7-10 STEM teachers identify similar things to the literature in terms of STEM skills. Of note, it is important to be aware that the phrase is typically taken to be broader than skills that pertain to STEM specifically.

Recommendation 1 – Clarify what is meant by the phrase STEM skills. While the phrase 'STEM skills' is used frequently by government ministers, people from industry, employers, teachers and so on, there is no clear consensus regarding what is actually meant by the term. It is also arguably too late to come to a universally agreed upon definition as the phrase is used so widely already (Bybee, 2016). Therefore, it is vital that in discussing STEM skills, or issues relating to STEM skills, that everybody in the conversation is clear about what they mean by the phrase to avoid talking at cross-purposes. Some people may just mean the literacy and/or disciplinary skills relevant to STEM disciplines (for example Siekmann & Korbel, 2016) whereas others will also include higher order thinking, interpersonal and intrapersonal skills (e.g. Aring, 2012; Carnevale et al., 2011; Prinsley & Baranyai, 2015). Thus it is recommended that a more precise term, such as 'technical skills' as used by Siekmann and Korbel (2016), be used when referring to STEM-specific skills.

Recommendation 2 – Review, widely disseminate and utilise the National STEM Education Strategy. The existence of a National STEM Education Strategy is beneficial in that it can provide help in addressing Recommendation 1 by clearly articulating the skills (among other things) that all teachers and students should be working towards. However, if it is to function in such a manner, it ought to more fully capture the range of skills typically seen to fall under the category of

STEM skills, including interpersonal and intrapersonal skills. A guiding document such as this ought to be updated regularly to reflect current literature perspectives. It also needs to be disseminated more widely. Whilst it is freely available on the internet, unless teachers are told of its existence, they are unlikely to find it. The author, who has been a STEM teacher since before the release of the strategy and held a leadership position related to STEM within a school, only discovered it through her doctoral research. This indicates that the distribution channels of the National STEM strategy have not been effective. Finally, every state and territory apart from the ACT has created their own STEM strategy since the release of the National strategy. Each of these strategies differ quite significantly from the National strategy and each other. This leads to a situation where states and territories are all working towards different goals. Despite the complexities of Australia's federal system, all jurisdictions working off one literature-informed, agreed upon and well-disseminated strategy would be a more effective way of helping Australian teachers to cultivate the development of the skills employers want in their future employees.

Research Question 2 – To what extent does the Australian Curriculum support the development of STEM skills?

- *Research Question 2a – What skills are made explicit in the general capabilities, cross-curriculum priorities and STEM learning areas of the Australian Curriculum?*
- *Research Question 2b – To what extent do Australian Year 7-10 STEM teachers feel the Australian Curriculum supports them in developing STEM skills in their students?*

The general capabilities, cross-curriculum priorities and STEM learning areas of the Australian Curriculum were all analysed. The general capabilities (literacy, numeracy, ICT capability, critical and creative thinking, personal and social capability, ethical understanding and intercultural understanding) are deemed to be of such importance and generality as to be suitable for development across all of the Australian Curriculum's learning areas. Literacy clearly has strong overlaps with the literacy domain of STEM skills from the literature, particularly given there is a focus placed on disciplinary literacies within its description. Numeracy and ICT are both examples of disciplinary skills while critical and creative thinking covers most of what was identified as higher order thinking skills from the literature. The personal and social capability has strong crossovers with interpersonal as well as intrapersonal skills, and thus all five domains of STEM skills identified from the literature are represented within the general capabilities. Ethical and intercultural understanding, whilst obviously vital for making worthwhile contributions to society, do not align with STEM skills directly.

While the general capabilities cover many STEM skills, the relative representation of each capability with the STEM learning areas is not high for Mathematics (except for numeracy) and Science. The Technologies fare much better with more significant contexts within which to develop the general capabilities. Thus, while a focus on the general capabilities provides opportunities to develop a range of skills, their relative underrepresentation within the Science and Mathematics curriculum means that teachers of these subjects would benefit from greater explicit guidance on how to meaningfully address them. This is reinforced by the fact that teachers who responded to the survey were less familiar with the general capabilities than the parts of the curriculum that pertain directly to their learning area such as content descriptions.

The cross-curriculum priorities (Aboriginal and Torres Strait Islander Histories and Cultures; Asia and Australia's Engagement with Asia and Sustainability) have very little room for development within the STEM learning areas. Within Science and the Technologies there is some linking of content descriptions to Sustainability. The other two cross-curriculum priorities are referred to minimally, especially within content descriptions. Whilst the proportion of elaborations tagged with the cross-curriculum priorities was, in some instances, a little higher than the content descriptions, they were very low across the board. This makes one wonder whether the term 'cross-curriculum priorities' is truly appropriate given their lack of applicability across several key learning areas. Again, teachers who responded to the survey were less familiar with these cross-curriculum priorities than the content details for their learning area which suggests teachers are not making efforts to explicitly refer to them on a regular basis.

In terms of the learning areas, the contrast between the style of content descriptions in Mathematics and Science, as opposed to the Technologies, was significant. The types of skills mentioned within each was also remarkably different. While the rationale and aims of all three learning areas mention a wide variety of skills, the content descriptions of Mathematics and Science are very focused upon knowledge to be acquired rather than skills to be developed. Technologies is the reverse of this, with content descriptions that are focused upon skills that can be applied across a wide variety of contexts. This is necessary within the Technologies curriculum as teachers are able to choose from a variety of contexts (e.g. engineering principles and systems, food and fibre production, food specialisations, and materials and technologies specialisations within the Design and Technologies course) through which to address the content descriptions. Thus, rather than articulating knowledge to be learnt within a given context, the content descriptions are much more generalised, skills-based, and adaptable to whichever context the teacher is using. While there was a limited number of responses from teachers in terms of how supportive they felt the curriculum to be for the development of STEM skills, the responses from teachers of Technologies were far more positive than for Mathematics or Science. This indicates that more support is needed at the curriculum level for Mathematics and Science teachers to help them to build skill development into their teaching and learning programs more effectively.

Taking the STEM learning areas together, there is a good coverage of the skills identified from the literature. However, different skills are the focus of the various components of a learning area's description. While the rationale and aims of Mathematics and Science, for instance, refer to their disciplinary literacy and the ability to apply knowledge and understanding to solve real-world problems, this does not flow through to the content descriptions and achievement standards. It is important therefore to consider with what aspects of the curriculum teachers are engaging because, even if the curriculum makes links to STEM skills, this will only be seen if it is within sections of the curriculum teachers refer to regularly. Teachers are less familiar with the rationale, aims, key ideas and structure of each learning area and more familiar with the scope and sequence, content descriptions, elaborations and achievement standards. This is probably because it is the latter components of the curriculum that drive the development of teaching programs. However, the relative lack of familiarity with the aims and rationale mean that teachers are not exposed to the broader range of skills indicated within these components of the curriculum, particularly with respect to Science and Mathematics. This runs the risk of the significance of disciplinary literacy and the applicability of these learning areas to real life being lost at the expense of an overemphasis of what students are to *know* rather than what they are to be able to *do.*

It must be remembered that states and territories have been implementing the Australian Curriculum on their own timeline. While teachers in the ACT and QLD have been implementing the new curriculum for years, other states and territories have only been doing so in the last year or two. The overrepresentation of teachers from the ACT and QLD in the survey respondents may therefore over-inflate the degree of familiarity that Australian teachers have with various aspects of the curriculum.

To what extent does the Australian Curriculum support the development of STEM skills? Taking the Australian Curriculum as a whole, most STEM skills identified in the framework of Chapter 5 Part 1a are featured somewhere. However, the level of support provided by the curriculum could certainly be improved. The general capabilities present significant cross-over with STEM skills, yet Mathematics and Science have the least amount of tagging of content descriptions with these capabilities. Teachers could be better supported through more explicit indication of contexts through which certain capabilities could be meaningfully addressed. The Mathematics and Science content descriptions are very knowledge-based with some reference to disciplinary-specific skills. If these content descriptions could be made to be less focused on knowledge and place greater emphasis on skills to be developed, as in the Technologies content descriptions, teachers may in turn place a greater focus on skill development.

Recommendation 3 – Place a more specific focus on skills within the Australian Curriculum. To help support teachers to develop these skills it is important that a wider range of skills is explicitly mentioned throughout all components of a learning area's curriculum, especially within the content description and achievement standard components. While the rationale and aims include a broad range of skills, this is not the part of the curriculum that teachers consult on a regular basis. Achievement standards guide what students need to demonstrate by the end of the year and content descriptions articulate in greater detail what is to be learnt within each topic. Infusing skills into these aspects of the curriculum may help teachers to ensure that they are giving due focus to skills as well as knowledge within their classrooms. Additionally, while the general capabilities are well chosen, are skills-based and have been linked to content descriptions via tagging, a clearer articulation of how each of them may be meaningfully developed within Science and Mathematics would be beneficial. The content descriptions within the Technologies could be used as a model for the improvement of the Science and Mathematics descriptions in terms of reducing the emphasis on what students are to know, to contexts in which key content knowledge can be applied. This would help to enable a greater range of skills to be explicitly written into the curriculum and therefore assist teachers to see the need to put due focus on skill development. The Australian Curriculum is being reviewed for the second time during 2020 (Karp, 2019), with a focus on mathematics and science first. Now is the perfect time for ACARA to think carefully about how the curriculum is presented and what adjustments could be made so that it may better support Australian STEM teachers.

Recommendation 4 – Place more emphasis on preparing students for the VET sector. Given that two thirds of jobs within STEM come from the VET sector (Baranyai et al., 2016), there ought to be a stronger focus on achieving a better balance between preparing students to study STEM subjects at university and encouraging students to consider a trade as a profession. The Design and Technologies curriculum incorporates many of the technical skills needed for STEM jobs in this sector, including operation analysis, technology design and system analysis and evaluation, which are not readily developed in any other learning area. Students should be encouraged to participate in an ASbA while still at school as this will help them to secure work more readily upon the completion of school. There has been a trend in Australia towards a sentiment that an undergraduate degree at least is required to get a secure, well-paying job, coupled with a devaluing of VET qualifications (Bolton, 2018; Karp, 2016). One way to help counter this is to promote work experience opportunities for students within contexts that do not all require degrees. Students should also be encouraged to consider commencing an AsBA to help them to realise that employment within the VET sector is just as valued as one secured after university and that, within Australia at least, the VET sector accounts for two thirds of STEM jobs (Baranyai et al., 2016).

Research Question 3 – To what extent do PISA and TIMSS assess STEM skills?

PISA and TIMSS were chosen for analysis as examples of how STEM skills are assessed because Australian students' results in these two tests are regularly used to decry Australia's performance on the world stage. Whenever Australia moves down in the rankings, which is unfortunately has been the case generally speaking since their inception in the year 2000, Australia's ability to compete internationally within an ever-increasing technological global economy is discussed in terms of concern, if not despair (Australian Industry Group, 2013; Marginson et al., 2013, OCS, 2014a). Given results in PISA and TIMSS are used to infer how students are going in STEM, it is important to know what these two tests do and do not assess.

The mathematics and science components of PISA are designed to assess mathematical literacy and scientific literacy respectively. However, aspects of the OECD's own definition of these two skills are simply unable to be addressed within a standardised test. Students are not asked questions that are *relevant* to their society or any current national or international challenges. Questions may look like a real-world problem as a context is used, but it is not personalised to students' lives (the same test is used worldwide) and thus it is just another set of test questions. Students cannot demonstrate that they are engaged citizens able to make well-reasoned decisions about real-world situations because they are not effectively being placed in a realistic situation. Students are sitting a test at school with no access to the information they would be able to consult in the real world when needing to make decisions (Sjoberg, 2012). Furthermore, no overly complex situation can be asked about as there is insufficient time to answer it and it could not be done in a standardised way. Furthermore, the students' ability to read differentiates students from the very first question. Several studies have demonstrated that high reading competence is associated with an advantage in the mathematics and science components of PISA as well as TIMSS. This indicates that the results are at least partially dependent upon students' reading literacy (Ajello, Caponera, & Palmerio, 2018). The OECD (2017) has recognised that as students have to read texts to complete all components of PISA that students' level of reading literacy will have some impact on their results in other parts of the test. However, while an effort has been made to make the questions as linguistically simple as possible, it is impossible to eliminate the impact of reading literacy upon performance more broadly and it reduces the complexity of questions able to be asked.

PISA's mathematical and scientific literacy components are tests which do not model real life and do not assess the whole of the OECD's own definitions of these disciplinary literacies. Furthermore, achievement is at least partially dependent upon students' reading ability, not their mathematical or scientific ability. The OECD describes PISA as an assessment of the skills students need for life (Schleicher, 2019), despite acknowledging that content knowledge underpins most of its questions. "Knowledge is not intended to be the main "hurdle"" (OECD, 2000, p. 95), however, if a student lacks that content knowledge it will most definitely be a hurdle for them. The IEA is at least upfront in saying that it assesses curriculum content and thus that TIMSS is a knowledge test. The question of whether both tests are necessary has also been raised in that, despite PISA and TIMSS using different measures of student assessment, they "appear to have measured essentially the same construct, namely general national cognitive ability" (Rindermann & Baumeister, 2015, p. 697). By using results in these tests when discussing skills, as is often done, it is easy to fall into the trap of assuming that educational achievement translates directly to skill levels, this is not necessarily the case (Aring, 2012)

The competencies and processes being assessed in the mathematics domain of PISA come almost exclusively from the disciplinary and higher order thinking domains of STEM skills identified in Chapter 5 Part 1a. Whilst communication is noted, it is very specifically referring to the communication of mathematical responses and is thus more disciplinary than interpersonal in nature. The three competencies being assessed within the science component draw all but exclusively on disciplinary and higher order thinking skills.

The inclusion of the problem solving domain provides another opportunity to determine students' higher order thinking skills, particularly as the OECD sought to avoid requiring disciplinary-specific knowledge to answer these questions. Therefore, it has the opportunity of being a better measure of cognitive ability as it is not affected, or at least not to the same extent, by students' lack of prerequisite knowledge. However, whether the inclusion of the collaborative aspect to the problem-solving domain is in anyway beneficial is highly questionable. The OECD indicates that a whole range of collaborative skills are to be assessed alongside problem solving skills. What is less clear is how students' ability in problem-solving is to be isolated from their collaborative ability. Furthermore, it is worth questioning whether collaboration with computer agents, where the student has a small number of fixed responses with which they can interact, is sufficiently representative of collaboration in the real-world to merit being included. As Herborn et al. (2018) indicate, the removal of the social component of collaboration by getting students to 'collaborate' with computer agents reduces the scope of processes that are involved in collaborating with other people, particularly in terms of interpersonal skills.

In terms of the five domains of STEM skills identified from the literature in Chapter 5 Part 1a, neither PISA nor TIMSS are well-suited to assessing students' skill level across all domains. While PISA seeks to assess disciplinary literacy, the extent to which it effectively does so is limited. What is well assessed in both tests are some disciplinary skills pertaining to mathematics and science, but only those that can be assessed within test conditions, none of the practical skills needed for most STEM jobs. Higher order thinking skills are arguably the most effectively assessed group of skills by both PISA and TIMSS.

Both tests require students to use a variety of mathematical and scientific skills in answering questions, but that is all from the disciplinary domain. Technology and engineering are not directly assessed. Thus skills related to only half of the STEM disciplines are included, reinforcing the S.t.e.M. approach to STEM (Blackley & Howell, 2015). Higher order thinking skills, in particular problem solving and reasoning, are assessed. But, as has been stated previously, the necessity of having the required background information means that higher order thinking skills are only effectively assessed for students with the relevant background knowledge. Interpersonal and intrapersonal skills are not assessed to a large extent by either test. Communication in terms of how the student expresses an answer is required, but is hardly representative of the full spectrum of forms of communication people need to demonstrate in the workplace. Additionally, while PISA had a domain focused on collaborative problem solving in their most recent iteration, the model of collaboration used is such that it is debateable whether the results give accurate insights into students' ability to collaborate in real-life. Intrapersonal skills are not assessed by either test and present greater challenges than cognitive skills for assessment in that it typically relies on self-reporting, observant reports or behavioural assessments (National Research Council, Board on Testing and Assessment, & Committee on the Assessment of 21st Century Skills, 2016). These skills are not assessed by PISA or TIMSS yet were listed by teachers when asked to list STEM skills and noted by employers as being very desirable (Prinsley & Baranyai, 2015; Tonkin, 2019).

In light of the very limited range of skills PISA and TIMSS assess, coupled with the level of reading literacy required to access the question, reliance on knowledge students bring into the test, and the absence of technology and engineering, there appears little justification for the use of PISA or TIMSS to comment on Australian students' STEM skills.

To what extent do PISA and TIMSS assess STEM skills? The two tests are best described as being primarily knowledge tests with some assessment of higher order thinking skills. PISA aims to assess mathematical and scientific literacy but can realistically only address a small component of their own definitions of these skills. Both tests assess a range of mathematical and scientific disciplinary skills. Higher order thinking skills such as problem solving and reasoning are assessed in both, but only for those students with the necessary disciplinary knowledge and reading literacy level required to interpret the question. Communication is only assessed to the extent of writing an answer and, while PISA endeavours to measure collaboration, the validity of how it does this is questionable. Neither test assesses intrapersonal skills. Thus, at best, PISA and TIMSS can be said to assess a small subset of STEM skills.

Recommendation 5 – Rely on data from appropriate metrics. It is important to ensure that whenever anything is to be measured, it is done by an appropriate metric. PISA and TIMSS are essentially knowledge tests, they do not measure a wide range of skills and the skills they do measure are assessed within a narrow construct, due to the nature of standardised tests. While the world is somewhat obsessed with league tables and comparing the achievement of their country with others, there is little to be gained from using results on a knowledge test to argue that skills are in a decline, particularly when Australia's results are only reported in terms of the reading, mathematical and scientific literacy domains, not problem solving. Less attention and emphasis ought to be given to PISA and TIMSS, at least when discussing STEM skills, as they simply do not measure these skills effectively and, in many cases, do not assess them at all.

For PISA to accurately assess the range of skills outlined in OECD frameworks, the reliance on background knowledge needs to be dramatically reduced so that it is skills and not knowledge being tested. The provision of information required to answer a question within the question itself can help to more accurately assess a students' ability to do something with that information, whether it be to solve a problem, evaluate information provided or so on. The IEA acknowledges that TIMSS is a knowledge test and so why it is being used to comment on STEM skills at all is unclear.

It is beyond the scope of this work to propose an alternative way of assessing the STEM skills identified in Chapter 5 Part 1a, particularly in an internationally standardised manner. However, it is important to remember that tests are not the only form, or indeed the best form, of assessment. While standardised test results enable easy comparison, teachers who know their students and provide them with authentic learning opportunities would be able to identify the skills in which the students have strengths and those skills that they need to develop.

Recommendations Summary

A summary of the five key recommendations made as a result of this study are listed below:

- Clarify what is meant be the phrase ‘STEM skills’ whenever it is used to make clear what skills are meant within that context. Alternatively, use a more accurate term for the skills that are meant, e.g. ‘STEM-specific skills’, ‘higher order thinking’ and so on so that the skills implied by the phrase are clear to all.
- Review, widely disseminate and utilise the National STEM Education Strategy and enrich it by incorporating relevant aspects from the current state/territory variations so that everyone can work from the National Strategy towards the same goal.
- Provide greater support to teachers of Mathematics and Science in particular by shifting the focus from having such a strong focus on knowledge to having at a clear focus on developing relevant skills as well within content descriptions. Make connections to general capabilities and cross-curriculum priorities clearer so that these may be addressed more effectively.
- Place more emphasis on preparing students for the VET sector as that is where the majority of Australia’s STEM workers are found. Ensure that students are aware of the full breadth of the STEM workforce and the types of jobs it encompasses and the path to get to those jobs. Facilitate more opportunities for work experience and/or ASbAs so that students are aware that university is not their only option.
- Rely on data from appropriate metrics, this requires an awareness of what the chosen metrics measure. PISA and TIMSS provide some insight into understanding of disciplinary content and higher order thinking skills. However, the wide range of skills often meant by the phrase STEM skills cannot possibly be assessed in a standardised test.

Limitations

It is important to acknowledge the limitations of each aspect of the study.

Research Question 1 – What are STEM skills?

Research Question 1a – What are STEM skills according to the literature? The lack of explicit detail in the literature regarding what is meant by the phrase STEM skills in general, let alone in schools, made composing a list of STEM skills suitable for development in schools quite challenging. STEM skills as required by employers were examined from government and industry reports due to the lack of sufficient specific detail in the conventional literature. Skills desired by employers were extrapolated back to skills that may be suitable for development in high schools. As an aim of education is to prepare students for future employment, this extrapolation is not a large issue in and of itself. However, the chronic lack of specification of what STEM skills are within a school context, and contradictory indications when they are given (e.g. the lack of similarity between various

Australian STEM education strategies as shown in Table 2) made the determination of a list of skills upon which to base the analysis of this study challenging and, to an extent, limited by what was found in the literature used in this section of the study.

Research Question 1b – What are STEM skills according to Australian Year 7-10 STEM teachers? A key limitation in the analysis of the survey results was the difficulty that was encountered in getting representative samples of responses from all states and territories and all educational sectors. Conducting educational research is notoriously difficult, and even though this was an online survey in which teachers only were participating (i.e. no visits to the school or student involvement), many jurisdictions required permissions at multiple levels. In the government school sector, some states and territories required approval by the relevant Department of Education, while others required permission from the Principal of any participating teacher's school. Some required both and others required neither. A similar experience was had in the Catholic education sector. As there is no governing body of Independent Schools it was up to the Principal in each instance. Therefore, every Independent School in Australia that included Years 7-10 was contacted via email to seek permission and, if granted, to request that the survey be forwarded to the relevant members of staff. As contacting Independent Schools could be done directly without requiring approval from a state/territory body, there was an overrepresentation of teachers from this sector. The delays arising from having to wait for approvals at various levels coupled with the impending end of the school year meant that the sample size was smaller than originally hoped for, but large enough from which to draw valid conclusions. It did, however, prevent any analysis at the state/territory or sector level.

Due to these sampling issues, the demographics of responding teachers were not entirely representative of the STEM teacher population of Australia. Most notably, there was a large overrepresentation of teachers from the ACT and an underrepresentation from VIC. There was also a large overrepresentation of respondents from Independent Schools while the Catholic sector was barely represented. These issues obviously limit the general applicability of results from the survey.

Research Question 2

Research Question 2a – What skills are made explicit in the general capabilities, cross-curriculum priorities and the STEM learning areas of the Australian Curriculum? While the Australian Curriculum was analysed as fully as possible for references to skills within not just the STEM learning areas but also the general capabilities and cross-curriculum priorities, this was only done within Years 7-10. This was done because these are the final four compulsory years of education within STEM disciplines. The study could have been extended further by an examination of the curriculum through Primary school to see how each learning area develops, though Years 7-10 are arguably sufficient to get an overview of the skills involved. Year 11 and 12 STEM subjects were not studied primarily because too much variation across the country exists in terms of how these learning areas are taught and assessed. However, it would be worth examining the skills outlined in the senior secondary curriculum documents to see if a broader range of skills is focused on in these years.

It is also important to note that only the online ACARA version of the Australian Curriculum was examined. Many jurisdictions have tailored the Australian Curriculum to fit in with how their state/territory's curriculum is typically structured. While they ought to still be the same in content, this was not verified because no analysis was completed at the state/territory level.

Research Question 2b – To what extent do Australian Year 7-10 STEM teachers feel the AC supports them in developing STEM skills in their students? As for Research Question 1b (survey), with the additional limitation that the inability to conduct any analysis at the state/territory level meant that any differences between the Australian Curriculum and the older state/territory curricula that were being phased out were unable to be identified.

Research Question 3

While every framework document for every round of testing for which results have been fully published was examined, it is important to note that the tests themselves were not. Although sample questions are interspersed through the framework documents, it proved impossible to obtain a complete set of questions and so frameworks alone were examined. Having said this, the frameworks are very detailed with respect to what competencies are assessed by each question type. Given the focus here is on the skills assessed rather than the structure of the tests themselves, this was not deemed a significant limitation for the current study.

Significance

Within Australia in 2019 the rate of growth of STEM jobs was 16.5% whereas non-STEM jobs were growing at 10.2% (Department of Education, Skills and Employment, 2019b). The growing STEM sector means that an increasing proportion of today's school students will be going into occupations requiring STEM skills. It is therefore of great importance for teachers to know what skills their students need to develop to increase their employability.

Collectively, this study is broad in its scope but also quite clearly focused on addressing its overall research question with a novel focus on Australia. A framework of STEM skills suitable for development within high schools has been developed for the first time and compared with the thoughts of Australian Year 7-10 teachers. This was done via a novel survey and provides a first look at what Australian high school STEM teachers think of when they hear the phrase STEM skills. This allows for some clarity around the phrase STEM skills but also emphasises why this clarity is needed. Such findings are internationally beneficial. Despite several previous assessments of STEM skills for employment, none took the thinking back a step to where many skills are first developed – the high school classroom.

Despite being implemented for the first time less than a decade ago, the Australian Curriculum is already under review for the second time (Karp, 2019). Analysis of the Australian Curriculum, coupled with feedback from Australian teachers on how supportive they find the curriculum to be within the STEM learning areas, provides invaluable information for the current review and for ACARA moving forward with its curriculum development and the support that it provides to teachers.

Finally, two international benchmarking tests, about which much is written every three or four years, were shown to be ineffective tools for the measurement of STEM skills. The range of skills that this phrase may in fact mean, particularly if it is as broad as the literature which led to the framework of skills presented, suggests there is no one test that could ever assess each of those things. Perhaps they do not need to be measured. Perhaps teachers and their students just need to know the skills students need to develop, be given a curriculum that supports them to do this, and then be left to do so, together.

Future research

There are several areas in which future research may be merited based on the research presented here. First, it would be worthwhile to get the perspectives of key stakeholders regarding what they mean when they use the phrase STEM skills. It would be beneficial to know the perspectives of people such as the Chief Scientist, Minister for Education, Minister for Jobs and Industrial Relations, Minister for Small and Family Business, Skills and Vocational Education, and Minister for Industry, Science and Technology to get the governmental perspective. It would also be prudent to do the same for groups who run STEM activities for students, STEM professional learning for teachers and so on. Finally, it would also be beneficial to know what students think the phrase STEM skills means, particularly those in Years 7-12 of secondary school and those at university. If all these groups are to be effectively working towards the same goal, then it is important to ensure that they are all clear about what they mean by the term STEM skills.

Curriculum documents of other nations could be examined for examples of mathematics and science curricula which place a larger focus on skills rather than just knowledge. While the Science Inquiry Skills strand of the Australian Curriculum outlines a variety of important disciplinary skills, and numeracy is a key focus within the mathematics curriculum, a broader range of skills could be included within their content descriptions and achievement standards. This may help teachers to put greater value on the development of skills and not just the coverage of knowledge.

It would be beneficial to run a similar survey to that done within this study, but with a larger number of respondents with appropriate representation from all jurisdictions and sectors, to verify the results obtained. It may also be prudent to conduct follow up interviews and/or focus groups to delve more deeply into perspectives shared in the survey. For example, teacher perspectives on STEM skills could be investigated more broadly and then, ideally with input from industry, the skills of particular importance within different parts of the job sector could be identified. These could then be used as the basis from which to run professional learning for teachers on the development of particular STEM skills within particular learning areas. Also, difficulties encountered by teachers in enacting the Australian Curriculum could also be the focus of professional learning made available to teachers.

Finally, further research could be done into alternative means of testing STEM skills, or a subset of them at least, in a more meaningful manner than can be obtained with PISA or TIMSS. NAPLAN is taken by Australian students in Years 3, 5, 7 and 9 (with a possible extension to Year 11 in the future) though its focus is on skills in general literacy and numeracy, only the latter of which is of particular significance within STEM. The National Assessment Program has also developed scientific literacy (NAP-SL) and ICT literacy (NAP-ICTL) tests that are completed by only a sample of students in Years 6 and 10 every three years (National Assessment Program, 2016a, 2016b). These could perhaps be explored as a means of assessing those two forms of literacy, but again this would give only very narrow insights into students' STEM skills. A test that examines each of the STEM skills identified from the literature does not exist, and this will probably remain the case as such a wide variety of skills are involved. However, it may be possible to assess collections of certain skills, such as different disciplinary literacies and problem-solving skills, perhaps more effectively than PISA or TIMSS. Disciplinary skills are, in many cases, hands-on practical skills and thus arguably ought to be assessed in that manner. Before any of these options are pursued though it is important to be sure that skills that are and are not being assessed are clearly articulated. It must also be acknowledged that some skills simply cannot be accurately assessed within a standardised test and that other means of assessment may need to be investigated to get an accurate measure of students' skills levels. Research into how formative and other means of non-standardised assessment, designed and administered by teachers, could be used to provide data on student achievement so that standardised tests are no longer valued or required would also be very worthwhile.

Conclusions

To conclude, some thoughts on the overarching question this research sought to address: how are Australian Year 7-10 teachers to develop and assess the STEM skills their students need to succeed in the workforce of today and tomorrow?

First and foremost, clarity around what is meant by the phrase STEM skills must be provided. The literature on STEM education makes a strong argument for the development of disciplinary literacies as well as STEM literacy throughout the community (Bybee, 2016; Timms et al., 2018). The literature pertaining to STEM skills of the workforce suggests that employers are looking for a broad range of skills including disciplinary, higher order thinking, interpersonal and intrapersonal skills (Aring, 2012; Carnevale et al., 2011; Prinsley & Baranyai, 2015). However, some suggest that the phrase STEM skills has come to mean such a disparate array of things that it ought not be used at all and that people should use more specific terms, such as technical skills for what have been termed disciplinary skills in this thesis (Siekmann & Korbel, 2016).

The skills identified from the literature in the framework made in Chapter 5 Part 1a were, with the exception of the literacy domain, also identified by teachers. These skills may be developed more effectively if teachers could be better supported with a stronger focus on skills in the Australian Curriculum. When the three key components of the Australian Curriculum including each part of the STEM learning areas are examined, the five domains of skills are touched on somewhere. The content components, with which teachers are most familiar, only maintain a focus on skills within the Technologies learning area. The content descriptions of Mathematics and Science are very much focused upon what content students are to learn, not the skills they are to develop, with the exception of the Science Inquiry Skills strand within Science. The general capabilities cover many of the STEM skills identified in Chapter 5 Part 1a and provide opportunities for skill development. However, despite being called *general* capabilities, little to no examples are given on how to address some of them within Mathematics and Science. Teachers would be better supported in the development of skills within their students if, first, the desired skills were made explicit and, second, that there was a focus on skills consistently through the curriculum. As the majority of jobs within STEM are in the VET sector, schools should also place an increased focus on encouraging students to consider undertaking an AsBA while at school and changing the culture at the school-level in Australia that a university degree is required to get decent job. Students need to know that university is not for everyone and that they can secure stable, well-paying jobs in the VET sector without a degree.

In terms of assessing STEM skills, teachers should be empowered to use their own knowledge of teaching, learning and assessment to track skill development. The STEM skills identified in Part 1a of Chapter 5, apart from higher order thinking and aspects of literacy and disciplinary skills, cannot be effectively assessed within a standardised test. While PISA and TIMSS may have a role to play somewhere in education, it is not in the assessment of STEM skills. The broader issues within the structure of these tests, the amount of press coverage they get, and the effect they have on educational changes are beyond the scope of this work. However, it has been demonstrated that they assess very few of the skills identified within Chapter 5 and that results need to be considered within the light of the reading literacy level and background knowledge requirements to answer a question, regardless of the skill/s it assesses.

In all, if STEM education is to remain a key focus within Australian education, teachers require more support and more trust must be placed in them. Skills needed by the workforce need to be made clear to educators at the secondary (and tertiary) level so that students are provided with opportunities to develop those skills before they try to enter the workforce. Once identified, those skills need to be made explicit across the curriculum so that the best chance is given for due focus to be placed on those skills. Finally, in the absence of an appropriate international standardised test to measure the types of skills employers want, teachers ought to be given more autonomy regarding how to keep track of their students' skill level. It is on a day to day basis within the classroom that students' skills will be best demonstrated, not within a standardised test.

References

Accreditation Board for Engineering and Technology. (2010). *Criteria for accrediting engineering programs*. Baltimore, MD: Author.

Achat-Mendes, C., Anfuso, C., Johnson, C., Shepler, B., & Hurst-Kennedy, J. (2019). Learning, leaders and STEM skills: Adaptation of the supplemental instruction model to improve STEM success and build transferable skills in undergraduate courses and beyond. *Journal of STEM Education: Innovates and Research, 20*(2), 14-23.

ACOLA Secretariat Ltd. (2016). *Securing Australia's future program: Summary report*. Retrieved from *http://www.acola.org.au/PDF/saf12/SAF12%20SummaryReport.pdf*

Ajello, A. M., Caponera, E., & Palmerio, L. (2018). Italian students' results in the PISA mathematics test: does reading competence matter? *European Journal of Psychology of Education, 33*, 505-520.

Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education, 95*(3), 518-542.

Allum, J. (2018). PISA and NAPLAN are 'warping' our schools. *The Sydney Morning Herald*. Retrieved from *https://www.smh.com.au/national/nsw/pisa-and-naplan-are-warping-our-schools-20180905-p501sn.html*

Amabile, T. (2013). Componential theory of creativity. In E. Kessler (Ed.), *Encyclopedia of management theory* (pp. 135-140). Thousand Oaks, CA: Sage.

Andrews, P., Atkinson, L., Ball, S. J., Barber, M., Beckett, L., Bernardi, J., . . . Zhao, Y. (2014). OECD and Pisa tests are damaging education worldwide - academics. *The Guardian*. Retrieved from *https://www.theguardian.com/education/2014/may/06/oecd-pisa-tests-damaging-education-academics*

Angier, N. (2010). STEM education has little to do with flowers. *The New York Times*. Retrieved from *http://www.nytimes.com/2010/10/05/science/05angier.html?_r=0*

Anthoney, S. F., & Armstrong, P. I. (2010). Individuals and environments: Linking ability and skill ratings with interests. *Journal of Counselling Psychology, 57*(1), 36-51.

Aring, M. (2012). *Paper commissioned for the EFA Global Monitoring Report 2012, Youth and skills: Putting education to work*. Retrieved from *http://unesdoc.unesco.org/images/0021/002178/217874e.pdf*

Aris, N., & Orcos, L. (2019). Educational robotics in the stage of secondary education: Empirical study on motivation and STEM skills. *Education Sciences, 9*(2), 1-16.

Australian Academy of Science. (2019). *Women in STEM decadal plan*. Retrieved from *https://www.science.org.au/files/userfiles/support/reports-and-plans/2019/gender-diversity-stem/women-in-STEM-decadal-plan-final.pdf*

Australian Bureau of Statistics. (2014). *Perspectives on education and training: Australians with qualifications in science, technology, engineering and mathematics (STEM), 2010-11*. Retrieved from *http://www.abs.gov.au/ausstats%5Cabs@.nsf/0/54B42BD3902EB8A2CA257C86000EA59A?Opendocument*

Australian Bureau of Statistics. (2018a). 4221.0 - Schools, Australia, 2017 - Explanatory notes. Retrieved from *http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4221.0Explanatory%20Notes12017?OpenDocument#*

Australian Bureau of Statistics. (2018b). 4221.0 - Schools, Australia, 2017 - Highlights. Retrieved from *http://www.abs.gov.au/ausstats/abs@.nsf/mf/4221.0*

Australian Bureau of Statistics. (2018c). 4221.0 - Schools, Australia, 2017 - Summary of findings. Retrieved from *https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4221.0main+features22017*

Australian Catholic University and Erebus International. (2008). *Literature review - Scoping study into approaches to student wellbeing*. Retrieved from *https://docs.education.gov.au/system/files/doc/other/appendix_1_literature_review.pdf*

Australian Curriculum, Assessment and Reporting Authority. (2011, August 3). Cross-curriculum priorities. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/cross-curriculum-priorities/*

Australian Curriculum, Assessment and Reporting Authority. (2012a, January 23). Critical and creative thinking. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/general-capabilities/critical-and-creative-thinking/*

Australian Curriculum, Assessment and Reporting Authority. (2012b). *Curriculum development process*. Retrieved from *http://www.acara.edu.au/_resources/ACARA_Curriculum_Development_Process_Version_6.0_-_04_April_2012_-_FINAL_COPY.pdf*

Australian Curriculum, Assessment and Reporting Authority. (2012c, January 23). Information and communication technology. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/general-capabilities/information-and-communication-technology-ict-capability/*

Australian Curriculum, Assessment and Reporting Authority. (2012d, January 23). Intercultural understanding. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/general-capabilities/intercultural-understanding/*

Australian Curriculum, Assessment and Reporting Authority. (2012e, January 23). Personal and social capability Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/general-capabilities/personal-and-social-capability/*

Australian Curriculum, Assessment and Reporting Authority. (2013a, January 31). Ethical understanding. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/general-capabilities/ethical-understanding/*

Australian Curriculum, Assessment and Reporting Authority. (2013b, January 31). Ethical understanding learning continuum. Retrieved from *http://docs.acara.edu.au/resources/General_capabilities_-_EU_-_learning_continuum.pdf*

Australian Curriculum, Assessment and Reporting Authority. (2013c, January 31). General capabilities. Retrieved from *http://www.australiancurriculum.edu.au/generalcapabilities/overview/introduction*

Australian Curriculum, Assessment and Reporting Authority. (2013d, January 31). Information and communication technology capability learning continuum. Retrieved from *http://docs.acara.edu.au/resources/General_capabilities_-_ICT_-_learning_continuum.pdf*

Australian Curriculum, Assessment and Reporting Authority. (2013e, January 31). Intercultural understanding learning continuum. Retrieved from *http://docs.acara.edu.au/resources/General_capabilities_-_ICU_-_learning_continuum.pdf*

Australian Curriculum, Assessment and Reporting Authority. (2013f, January 31). Literacy. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/general-capabilities/literacy/*

Australian Curriculum, Assessment and Reporting Authority. (2013g, January 31). Numeracy. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/general-capabilities/numeracy/*

Australian Curriculum, Assessment and Reporting Authority. (2013h, January 31). Numeracy learning continnum. Retrieved from *http://docs.acara.edu.au/resources/General_capabilities_-_NUM_-_learning_continuum.pdf*

Australian Curriculum, Assessment and Reporting Authority. (2013i, January 31). Personal social capability learning continuum. Retrieved from *http://docs.acara.edu.au/resources/General_capabilities_-PSC_-_learning_continuum.pdf*

Australian Curriculum, Assessment and Reporting Authority. (2014a, October 8). Aboriginal and Torres Strait Islander histories. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/cross-curriculum-priorities/aboriginal-and-torres-strait-islander-histories-and-cultures/*

Australian Curriculum, Assessment and Reporting Authority. (2014b, October 8). Asia and Australia's engagement with Asia. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/cross-curriculum-priorities/asia-and-australia-s-engagement-with-asia/*

Australian Curriculum, Assessment and Reporting Authority. (2014c). *State and territory implementation of the foundation to year 10 Australian curriculum*. Retrieved from *https://acaraweb.blob.core.windows.net/resources/State_and_Territory_F-10_Australian_Curriculum_Implementation_Timelines_August_2014.pdf*

Australian Curriculum, Assessment and Reporting Authority. (2014d, October 8). Sustainability. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/cross-curriculum-priorities/sustainability/*

Australian Curriculum, Assessment and Reporting Authority. (2015a, October 18). Design and Technologies. Retrieved from *https://australiancurriculum.edu.au/f-10-curriculum/technologies/design-and-technologies/?year=12976&year=12977&strand=Design+and+Technologies+Knowledge+and+Understanding&strand=Design+and+Technologies+Processes+and+Production+Skills&capability=ignore&capability=Literacy&capability=Numeracy&capability=Information+and+Communication+Technology+%28ICT%29+Capability&capability=Critical+and+Creative+Thinking&capability=Personal+and+Social+Capability&capability=Ethical+Understanding&capability=Intercultural+Understanding&priority=ignore&priority=Aboriginal+and+Torres+Strait+Islander+Histories+and+Cultures&priority=Asia+and+Australia%E2%80%99s+Engagement+with+Asia&priority=Sustainability&elaborations=true&elaborations=false&scotterms=false&isFirstPageLoad=false*

Australian Curriculum, Assessment and Reporting Authority. (2015b, October 18). Design and Technologies: Aims. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/technologies/design-and-technologies/aims/*

Australian Curriculum, Assessment and Reporting Authority. (2015c, October 18). Design and Technologies: Rationale. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/technologies/design-and-technologies/rationale/*

Australian Curriculum, Assessment and Reporting Authority. (2015d, October 18). Design and Technologies: Structure. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/technologies/design-and-technologies/structure/*

Australian Curriculum, Assessment and Reporting Authority. (2015e, October 18). Digital Technologies. Retrieved from *https://australiancurriculum.edu.au/f-10-curriculum/technologies/digital-technologies/?year=12986&year=12987&strand=Digital+Technologies+Knowledge+and+Understanding&strand=Digital+Technologies+Processes+and+Production+Skills&capability=ignore&capability=Literacy&capability=Numeracy&capability=Information+and+Communication+Technology+%28ICT%29+Capability&capability=Critical+and+Creative+Thinking&capability=Personal+and+Social+Capability&capability=Ethical+Understanding&capability=Intercultural+Understanding&priority=ignore&priority=Aboriginal+and+Torres+Strait+Islander+Histories+and+Cultures&priority=Asia+and+Australia%E2%80%99s+Engagement+with+Asia&priority=Sustainability&elaborations=true&elaborations=false&scotterms=false&isFirstPageLoad=false*

Australian Curriculum, Assessment and Reporting Authority. (2015f, October 18). Digital Technologies: Aims. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/technologies/digital-technologies/aims/*

Australian Curriculum, Assessment and Reporting Authority. (2015g, October 18). Digital Technologies: Rationale. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/technologies/digital-technologies/rationale/*

Australian Curriculum, Assessment and Reporting Authority. (2015h, October 18). Digital Technologies: Structure. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/technologies/digital-technologies/structure/*

Australian Curriculum, Assessment and Reporting Authority. (2015i, October 18). Mathematics. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/mathematics/?year=11758&year=11759&year=11760&year=11761&year=11762&strand=Number+and+Algebra&strand=Measurement+and+Geometry&strand=Statistics+and+Probability&capability=ignore&capability=Literacy&capability=Numeracy&capability=Information+and+Communication+Technology+(ICT)+Capability&capability=Critical+and+Creative+Thinking&capability=Personal+and+Social+Capability&capability=Ethical+Understanding&capability=Intercultural+Understanding&priority=ignore&priority=Abori*

ginal+and+Torres+Strait+Islander+Histories+and+Cultures&priority=Asia+and+Australia%u2019s+Engagement+with+Asia&priority=Sustainability&elaborations=true&elaborations=false&scotterms=false&isFirstPageLoad=false&page=1

Australian Curriculum, Assessment and Reporting Authority. (2015j, October 18). Mathematics: Aims. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/mathematics/aims/*

Australian Curriculum, Assessment and Reporting Authority. (2015k, October 18). Mathematics: Key Ideas. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/mathematics/key-ideas/*

Australian Curriculum, Assessment and Reporting Authority. (2015l, October 18). Mathematics: Rationale. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/mathematics/rationale/*

Australian Curriculum, Assessment and Reporting Authority. (2015m, October 18). Mathematics: Structure. Retrieved from *http://www.australiancurriculum.edu.au/mathematics/structure*

Australian Curriculum, Assessment and Reporting Authority. (2015n, October 18). Science. Retrieved from *https://australiancurriculum.edu.au/f-10-curriculum/science/?year=12007&year=12008&year=12009&year=12010&strand=Science+Understanding&strand=Science+as+a+Human+Endeavour&strand=Science+Inquiry+Skills&capability=ignore&capability=Literacy&capability=Numeracy&capability=Information+and+Communication+Technology+%28ICT%29+Capability&capability=Critical+and+Creative+Thinking&capability=Personal+and+Social+Capability&capability=Ethical+Understanding&capability=Intercultural+Understanding&priority=ignore&priority=Aboriginal+and+Torres+Strait+Islander+Histories+and+Cultures&priority=Asia+and+Australia%E2%80%99s+Engagement+with+Asia&priority=Sustainability&elaborations=true&elaborations=false&scotterms=false&isFirstPageLoad=false*

Australian Curriculum, Assessment and Reporting Authority. (2015o, October 18). Science: Aims. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/science/aims/*

Australian Curriculum, Assessment and Reporting Authority. (2015p, October 18). Science: Key Ideas. Retrieved from *http://australian-curriculum.org/science/key-ideas*

Australian Curriculum, Assessment and Reporting Authority. (2015q, October 18). Science: Rationale. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/science/rationale/*

Australian Curriculum, Assessment and Reporting Authority. (2015r, October 18). Science: Structure. Retrieved from *http://www.australiancurriculum.edu.au/science/curriculum/f-10?layout=1*

Australian Curriculum, Assessment and Reporting Authority. (2015s, October 18). Structure. Retrieved from *https://australiancurriculum.edu.au/f-10-curriculum/structure/*

Australian Curriculum, Assessment and Reporting Authority. (2015t, October 18). Technologies: Introduction. Retrieved from *http://www.australiancurriculum.edu.au/technologies/introduction*

Australian Curriculum, Assessment and Reporting Authority. (2015u, October 18). Technologies: Key Ideas. Retrieved from *https://www.australiancurriculum.edu.au/f-10-curriculum/technologies/key-ideas/*

Australian Curriculum, Assessment and Reporting Authority. (2015v, October 18). Technologies: Structure. Retrieved from *http://www.australiancurriculum.edu.au/technologies/structure*

Australian Curriculum, Assessment and Reporting Authority. (2016). *ACARA STEM connections project report*. Retrieved from *http://resources.australiancurriculum.edu.au/stemreport*

Australian Curriculum, Assessment and Reporting Authority. (2018a, December 14). About the Australian Curriculum. Retrieved from *https://www.australiancurriculum.edu.au/about-the-australian-curriculum/*

Australian Curriculum, Assessment and Reporting Authority. (2018b). Australian Curriculum. Retrieved from *https://australiancurriculum.edu.au/*

Australian Curriculum, Assessment and Reporting Authority. (2018c). New science elaborations. Retrieved from *https://australiancurriculum.edu.au/news/2018/10/new-science-elaborations/*

Australian Curriculum, Assessment and Reporting Authority. (2019). My School. Retrieved from *https://www.myschool.edu.au/*

Australian Government Australian Apprenticeships. (2015). Australian school-based apprenticeships. Retrieved from *https://www.australianapprenticeships.gov.au/programs/australian-school-based-apprenticeships*

Australian Government Department of Education. (2014). *Review of the Australian Curriculum: Final report*. Retrieved from Canberra: *https://docs.education.gov.au/documents/review-australian-curriculum-final-report*

Australian Industry Group. (2013). *Lifting our science, technology, engineering and maths (STEM) skills*. Retrieved from *http://pandora.nla.gov.au/pan/140763/20130603-1549/www.aigroup.com.au/portal/binary/com.epicentric.contentmanagement.servlet.ContentDeliveryServlet/LIVE_CONTENT/Publications/Reports/2013/Ai_Group_Skills_Survey_2012-STEM_FINAL_PRINTED.pdf*

Australian Industry Group. (2015). *Progressing STEM skills in Australia*. Retrieved from *http://cdn.aigroup.com.au/Reports/2015/14571_STEM_Skills_Report_Final_-.pdf*

Australian Industry Group. (2016). Low literacy and numeracy skills plaguing employers. Retrieved from *https://www.aigroup.com.au/policy-and-research/mediacentre/releases/cb2c00d2-9506-e611-80d0-00505680033d/*

Australian Industry Group. (2017). *Strengthening school - Industry STEM skills partnerships: Final project report*. Retrieved from *http://cdn.aigroup.com.au/Reports/2017/AiGroup_OCS_STEM_Report_2017.pdf?_cldee=Z3JhaGFtLnR1cm5lckBhaWdyb3VwLmNvbS5hdQ%3d%3d&recipientid=contact-5622c0dde9fb4f51a93872c8a5920899-7f38d9c6cb0c480e82a61b85a9b654c3&esid=0aefa8e5-c750-e711-80d1-0050568007a5*

Australian Industry Group. (2018). *Skilling: A national imperative*. Retrieved from *https://cdn.aigroup.com.au/Reports/2018/Survey_Report_WFDNeeds_Skilling_Sept2018.pdf*

Australian Institute for Teaching and School Leadership. (2017). Australian teacher workforce data strategy. Retrieved from *https://www.aitsl.edu.au/research/australian-teacher-workforce-data/how-does-it-work*

Bagshaw, E. (2016). Australian school students two years behind world's best *The Sydney Morning Herald*. Retrieved from *http://www.smh.com.au/national/education/australian-school-students-two-years-behind-worlds-best-performing-systems-20161206-gt4w8p.html*

Baranyai, K., Bowles, J., Hassan, S., Prinsley, R., Smith, P., & Walter, C. (2016). *Australia's STEM workforce*. Retrieved from *http://www.chiefscientist.gov.au/2016/03/report-australias-stem-workforce/*

Beech, A. (2018). High schools to get specialist teachers who studied maths, science at university under Federal Government plan. *ABC News*. Retrieved from *http://www.abc.net.au/news/2018-07-09/every-high-school-to-get-specialist-maths-science-teachers/9956880*

Berry, M., Chalmers, C., & Chandra, V. (2012). *STEM futures and practice, can we teach STEM in a more meaningful and integrated way?* Paper presented at the 2nd International STEM in Education Conference, Beijing, China. *https://eprints.qut.edu.au/57318/*

Birmingham, S. (2018). Address at the conference of the Australian science teachers association (CONASTA) [Press release]. Retrieved from *https://ministers.education.gov.au/birmingham/address-conference-australian-science-teachers-association-conasta*

Birrell, B. (2014). Too few or perhaps too many STEM graduates. *Australian Universities' Review, 56*(2), 71-78.

Blackley, S., & Howell, J. (2015). A STEM aarrative: 15 years in the making. *Australian Journal of Teacher Education, 40*(7), 102-112.

Bolton, R. (2018). Skills crisis looms as VET training slides in favour of university degrees. *Financial Review*. Retrieved from *https://www.afr.com/policy/health-and-education/vocational-training--the-poor-cousin-in-australian-education-20180109-h0fpdv*

Breakspear, S. (2012). *The policy Impact of PISA: An exploration of the normative effects of international benchmarking in school system performance*. Retrieved from

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112*(1), 3-11.

Brown, R. (2018). More training and support can help STEM education live up to the demand. Retrieved from *https://www.createdigital.org.au/national-support-stem-education-demand/*

Buckingham, J. (2016). Why Australia's PISA results are a catastrophe. *Australian Financial Review*. Retrieved from *http://www.afr.com/opinion/columnists/why-australias-pisa-results-are-a-catastrophe-20161206-gt536q*

Bybee, R. B. (2016). *The case for STEM education: challenges and opportunities*. Australia: Hawker Brownlow Education.

Camilli, G., & Hira, R. (2019). Introduction to special issue - STEM qorkforce: STEM education and the post-scientific society. *Journal of Science Education and Technology, 28*, 1-8.

Carnevale, A. P., Smith, N., & Melton, M. (2011). *STEM*. Retrieved from *https://cew.georgetown.edu/wp-content/uploads/2014/11/stem-complete.pdf*

Chapman, S., & Vivian, R. (2017). *Engaging the future of STEM*. Retrieved from *https://cew.org.au/wp-content/uploads/2017/03/Engaging-the-future-of-STEM.pdf*

Charette, R. N. (2013). The STEM crisis is a myth. Retrieved from *http://spectrum.ieee.org/at-work/education/the-stem-crisis-is-a-myth*

Cheng, L. (2019). *T3D printing integration in K-12 science classrooms: The relationship with students' STEM motivation, 21st century skills and interest in STEM careers.* (Docotor of Philosopy). University of Florida, ProQuest Dissertations Publishing.

Conifer, D. (2016). Australia crashing down international leaderboard for education, falling behind Kazakhstan. *ABS News*. Retrieved from *http://www.abc.net.au/news/2016-11-30/australia-declines-in-global-education-report/8077474*

Crook, S. (2018). Fixing the shortage of specialist science and maths teachers will be hard, not impossible. *The Conversation*. Retrieved from *https://theconversation.com/fixing-the-shortage-of-specialist-science-and-maths-teachers-will-be-hard-not-impossible-99651*

Cunningham, W., & Villasenor, P. (2016). *Employer voices, employer demands, and implications for public skills development policy connecting the labor and education sectors*. Retrieved from *https://openknowledge.worldbank.org/bitstream/handle/10986/23921/Employer0voice0nd0education0sectors.pdf?sequence=1&isAllowed=y*

Daly, A., Lewis, P., Corliss, M., & Heaslip, T. (2011). The private rate of return to a unviersity degree in Australia. *Australian Journal of Education, 59*(1), 97-112.

Daugherty, M. K. (2013). The prospect of an "A" in STEM education. *Journal of STEM Education, 14*(2), 12-15.

Deloitte Access Economics. (2014). *Australia's STEM workforce: a survey of employers*. Retrieved from *http://www.chiefscientist.gov.au/wp-content/uploads/DAE_OCS-Australias-STEM-Workforce_FINAL-REPORT.pdf*

Department of Education. (2014). *Review of the Australian Curriculum - Initial Australian government response*. Retrieved from *https://docs.education.gov.au/system/files/doc/other/initial_australian_government_response_final_0.pdf*

Department of Education, Skills and Employment. (2019a). Australian Curriculum. Retrieved from *https://www.education.gov.au/australian-curriculum-0*

Department of Education, Skills and Employment. (2019b). STEM jobs are growing faster than other jobs. Retrieved from *https://www.employment.gov.au/newsroom/stem-jobs-are-growing-faster-other-jobs*

Department of Industry, Science, Energy and Resources. (2019). *Advancing women in STEM*. Retrieved from *https://www.industry.gov.au/sites/default/files/2019-04/advancing-women-in-stem.pdf*

Department of Industry and Science. (2015). *Vision for a science nation. Responding to science, technology, engineering and mathematics: Australia's future*. Retrieved from *http://www.science.gov.au/scienceGov/news/Documents/VisionForAScienceNationRespondingToSTEMAustraliasFuture.pdf*

Dinham, S., & Lomas Scott, C. (2012). Our Asian schooling infatuation: the problem of PISA envy. *The Conversation*. Retrieved from *http://theconversation.com/our-asian-schooling-infatuation-the-problem-of-pisa-envy-9435*
Duffy, C. (2020). University fees to be overhauled, some course costs to double as domestic student places boosted. Retrieved from *https://www.abc.net.au/news/2020-06-19/university-fees-tertiary-education-overhaul-course-costs/12367742*
Dumas, D., Schmidt, L. C., & Alexander, P. A. (2016). Predicting creative problem solving in engineering design. *Thinking Skills and Creativity*(September), 50-66.
Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103-120.
Education Council. (2015). *National STEM school education strategy: A comprehensive plan for science, technology, engineering and mathematics education in Australia*. Retrieved from *http://www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/National%20STEM%20School%20Education%20Strategy.pdf*
Eppes, T. A., Milanovic, I., & Sweitzer, H. F. (2012). Strengthening capstone skills in STEM programs. *Innovative Higher Education, 37*, 3-10.
Feniger, Y., & Lefstein, A. (2014). How not to reason with PISA data: an ironic investigation. *Journal of Educational Policy, 29*(6), 845-855.
Fensham, P. (2004). Increasing the relevance of science and technology education for all students in the 21st century. *SCience Education International, 15*(1), 7-26.
Fleishman, E., Costanza, D., & Marshall-Mies, J. (1999). Abilities. In N. Peterson, M. Mumford, W. Borman, P. Jeanneret, & E. Fleishman (Eds.), *An Occupational information system for the 21st century: The development of O*NET* (pp. 175-195). Washington DC: American Psychological Association.
Forster, M. (2004). *Higher order thinking skills*. Retrieved from *https://research.acer.edu.au/cgi/viewcontent.cgi?article=1004&context=resdev*
Freeman, C., O'Malley, K., & Eveleigh, F. (2014). *Australian teachers and the learning environment - An analysis of teacher response to TALIS 2013 - Final Report*. Retrieved from *https://docs.education.gov.au/system/files/doc/other/talis_report-online_0_0.pdf*
Froschauer, L. (2016). STEAM: Beyond the acronym. *Science and Children, 53*(6), 5.
Germain-McCarthy, Y. (2013). *Bring NCTM standards to life: Best practices, high school*. New York: Routledge.
Gillard, J. (2012). National plan for school improvement [Press release]. Retrieved from *http://www.pm.gov.au/press-office/national-plan-school-improvement*
Gough, A. (2015). STEM policy and science education: scientistic curriculum and sociopolitical silences. *Cultural Studies of Science Education, 10*(2), 445-458.
Grégoire, J. (2016). Understanding creativity in mathematics for improving mathematical education. *Journal of Cognitive Education and Psychology, 15*(1), 24-36.
Grek, S. (2009). Governing by the numbers: the PISA 'effect' in Europe. *Journal of Education Policy, 24*(1), 23-37.
Gronmo, L. S., Lindquist, M., Arora, A., & Mullis, I. V. S. (2013). TIMSS 2015 mathematics framework. In I. V. S. Mullis & M. O. Martin (Eds.), *TIMSS 2015 Assessment Framework*. Retrieved from *https://timssandpirls.bc.edu/timss2015/frameworks.html*
Harris, M. (2014). The STEM shortage paradox. *Physics World, 27*(10), 56-59.
Henebery, B. (2019). Expert sounds the alarm on Australia's STEM skills gap. *The Educator: Higher Degree Edition*. Retrieved from *https://www.theeducatoronline.com/he/news/expert-sounds-the-alarm-on-australias-stem-skills-gap/268354*
Herborn, K., Stadler, M., Mustafic, M., & Greiff, S. (2018). The assessment of collaborative problem solving in PISA 2015: Can computer agents replace humans? *Computers in Human Behavior*. doi:*https://doi.org/10.1016/j.chb.2018.07.035*
Herschbach, D. R. (2011). The STEM initiative: Constraints and challenges. *Journal of STEM Teacher Education, 48*(1), 96-122.
Hickey, C. (2019). NAPLAN: Comprehensive review needed. *Independent Education, 49*(1), 14-15.
Hill, C. T. (2019). STEM Is not enough: Education for success in the post-scientific society. *Journal of Science Education and Technology, 28*(69-73).

Hira, R. (2019). Outsourcing STEM jobs: What STEM educators should know. *Journal of Science Education and Technology, 28*, 41-51.

Holmlund, T. D., Lesseig, K., & Slavit, D. (2018). Making sense of "STEM education" in K-12 contexts. *International Journal of STEM Education, 5*(32), 1-18.

Hunjan, R., & Blumer, C. (2016). Australian schools are in ‘absolute decline’ globally, says PISA report *ABC News*. Retrieved from *http://www.abc.net.au/news/2016-12-06/australian-school-performance-in-absolute-decline-globally/8098028*

Hunter, F. (2018). 'Too much being taught': Tehan says national curriculum is overcrowded. *The Sydney Morning Herald*. Retrieved from *https://www.smh.com.au/politics/federal/too-much-being-taught-tehan-says-national-curriculum-is-overcrowded-20181209-p50l5s.html*

Iliopoulos, E., Morrissey, N., Baryeh, K., & Polyzios, I. (2018). Correlation between workplace learning and job satisfaction of NHS healthcare professionals. *British Journal of Healthcare Management, 24*(5), 226-233.

International Association for the Evaluation of Educational Acheivement. (1995). *TIMSS IEA's Third International Mathematics and Science Study, TIMSS science items: Released set for population 2 (aeventh and eighth Grades)*. Retrieved from *https://timssandpirls.bc.edu/timss1995i/TIMSSPDF/BSItems.pdf*

International Association for the Evaluation of Educational Acheivement. (1999). *TIMSS 1999 science items released set for eighth grade*. Retrieved from *https://timssandpirls.bc.edu/timss1999i/pdf/t99science_items.pdf*

International Association for the Evaluation of Educational Acheivement. (2016). About TIMSS & PIRLS international study centre. Retrieved from *http://timssandpirls.bc.edu/about.html*

International Association for the Evaluation of Educational Acheivement. (2020). Trends in International Mathematics and Science Study. *IEA Studies*. Retrieved from *https://www.iea.nl/studies/iea/timss#section-22*

International Association for the Evaluation of Educational Achievement. (1995). *TIMSS IEA's Third International Mathematics and Science Study, TIMSS mathematics items: Released set for population 2 (seventh and eighth Grades)*. Retrieved from *https://timssandpirls.bc.edu/timss1995i/TIMSSPDF/BMItems.pdf*

International Association for the Evaluation of Educational Achievement. (1999). *TIMSS 1999 mathematics items released set for eighth grade*. Retrieved from *https://timssandpirls.bc.edu/timss1999i/pdf/t99math_items.pdf*

International Society for Technology in Education. (2000). *National educational technology standards*. Washington DC: International Society for Technology in Education.

International Technology Education Association. (2007). *Standards for technological literacy: Content for the study of technology* (3rd ed.). Reston, VA: Author.

Jacobson, S. K. (2009). *Communication skills for conservation professsionals* (2nd ed.). Washington DC: Island Press.

Johnson, C. C. (2013). Conceptualising integrated STEM education. *School Science and Mathematics, 113*(8), 367-368.

Jolly, A. (2014). STEM vs. STEAM: Do the arts belong? *Education Week Teacher,* (November 18). Retrieved from *https://www.edweek.org/tm/articles/2014/11/18/ctq-jolly-stem-vs-steam.html*

Jones, L. R., Wheeler, G., & Centurino, V. A. S. (2013). TIMSS 2015 science framework. In I. V. S. Mullis & M. O. Martin (Eds.), *TIMSS 2015 Assessment Framework*. Retrieved from *https://timssandpirls.bc.edu/timss2015/frameworks.html*

Karatas, F. O., Bodner, G. M., & Unal, S. (2016). First-year engineering students' views on the nature of engineering: implications for engineering programmes. *European Journal of Engineering Education, 41*(1), 1-22.

Karp, P. (2016). Too many graduates: universities chief warns against degrees for all. *The Guardian*. Retrieved from *https://www.theguardian.com/australia-news/2016/aug/01/too-many-graduates-universities-chief-warns-against-degrees-for-all*

Karp, P. (2019). Coalition to review Australian education curriculum in bid to reverse fall in student results. *The Guardian*. Retrieved from *https://www.theguardian.com/australia-news/2019/dec/12/coalition-to-review-australian-education-curriculum-in-bid-to-reverse-fall-in-student-results*

Kaspura, A. (2017). *Engineers make things happen: The need for an engineering pipeline strategy*. Retrieved from *https://www.engineersaustralia.org.au/sites/default/files/resources/Public%20Affairs/Engineers%20Make%20Things%20Happen.pdf*

Kazén, M., Kuhl, J., & Leicht, E.-M. (2015). When the going gets tough...: Self-motivation is associated with invigoration and fun. *Psychological Research, 79,* 1064-1076.

Knott, M. (2016a, 7 August 2016). 'I'm nervous, we are in uncharted territory': why Australia needs fewer science graduates. *The Sydney Morning Herald*. Retrieved from *http://www.smh.com.au/federal-politics/political-news/im-nervous-we-are-in-uncharted-territory-why-australia-needs-fewer-science-graduates-20160807-gqmy19.html*

Knott, M. (2016b, 30 November). Wake-up call: Australian students fall behind Kazakhstan in maths and science rankings. *The Sydney Morning Herald*. Retrieved from *www.smh.com.au/federal-politics/political-news/wakeup-call-australian-students-fall-behind-kazakhstan-in-maths-and-science-rankings-20161129-gszvt1.hmtl*

Krajcik, J., & Delen, I. (2017). Engaging learners in STEM education. *Eesti Haridusteaduste Ajakiri, 5*(1), 35-58.

Kramer, M., Tallant, K., Goldberger, A., & Lebus, F. (2015). *The global STEM paradox*. Retrieved from *https://www.nyas.org/media/15805/global_stem_paradox.pdf*

Lau, K.-C. (2009). A critical examination of PISA's assessment on scientific literacy. *International Journal of Science and Mathematics Education, 7,* 1061-1088.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assesment of learners' conceptions of nature of science. *Journal of Research in Science Teaching, 39*(6), 497-521.

Lodico, M. G., Spaulding, D. T., & Voegtle, K. H. (2006). *Methods in educational research: From theory to practice*. San Francisco: Jossey-Bass.

Logan, M. R. (2012). *Science as a human endeavour: teachers' understanding relating to the implementation of this element into primary and secondary classrooms.* Paper presented at the 43rd Annual Australiasian Science Education Research Association, Sunshine Coast, Australia.

Lokan, J., Greenwood, L., & Cresswell, J. (2001). *15-Up and counting, reading, writing, reasoning: How literate are Australian students?: The PISA 2000 survey of students' reading, mathematical and scientific literacy skills*. Retrieved from Melbourne: *https://research.acer.edu.au/indigenous_education/7/*

Lowell, B. L., & Salzman, H. (2007). *Into the eye of the storm: Assessing the evidence on science and engineering education, quality, and workforce demand*. Retrieved from *http://www.urban.org/sites/default/files/alfresco/publication-pdfs/411562-Into-the-Eye-of-the-Storm.PDF*

Loyens, S., Magda, J., & Rikers, R. (2008). Self-directed learning in problem-based learning and its relationships with self-regulated learning. *Educational Psychology Review, 20*(4), 411-427.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparisons*. Retrieved from *http://www.acola.org.au/PDF/SAF02Consultants/SAF02_STEM_%20FINAL.pdf*

Marshall, D. (2013). There's a critical difference between creativity and innovation. *Business Insder Australia,* (April). Retrieved from *https://www.businessinsider.com.au/difference-between-creativity-and-innovation-2013-4?r=US&IR=T*

McComas, W. F., Clough, M. P., & Almazroa, H. (1998). The nature of science in science education: An introduction. *Science & Education, 7,* 511-532.

McComas, W. F., Clough, M. P., & Almazroa, H. (2002). The role and character of the nature of science in science education. In W. F. McComas (Ed.), *The Nature of Science in Science Education* (pp. 3-40). New York: Kluwer Academic Publishers.

McGrath, K. F., & van Bergen, P. (2017). Male teachers are an endangered species in Australia: new research. *The Conversation*. Retrieved from *https://theconversation.com/male-teachers-are-an-endangered-species-in-australia-new-research-83464*

Mullis, I. V. S., Martin, M. O., & Foy, P. (2008). *TIMSS 2007 international mathematics report: Findings from IEA's Trends in International Mathematics and Science Study at the fourth and* *eighth grades*. Retrieved from United States: *http://timss.bc.edu/timss2007/PDF/TIMSS2007_InternationalMathematicsReport.pdf*

Mullis, I. V. S., Martin, M. O., Ruddock, G. J., O'Sullivan, C. Y., Arora, A., & Erberber, E. (2005). *TIMSS 2007 assessment frameworks*. Retrieved from *https://timssandpirls.bc.edu/TIMSS2007/index.html*

Mullis, I. V. S., Martin, M. O., Ruddock, G. J., O'Sullivan, C. Y., & Preuschoff, C. (2009). *TIMSS 2011 assessment frameworks*. Retrieved from *https://timssandpirls.bc.edu/timss2011/frameworks.html*

Mullis, I. V. S., Martin, M. O., Smith, T. A., Garden, R. A., Gregory, K. D., Gonzalez, E. J., . . . O'Connor, K. M. (2003). *TIMSS assessment frameworks and specifications 2003*. Retrieved from *https://timssandpirls.bc.edu/timss2003i/frameworks.html*

Murphy, S., MacDonald, A., Danaia, L., & Wang, C. (2019). An analysis of Australian STEM education strategies. *Policy Futures in Education, 17*(2), 122-139.

National Assessment Governing Board. (2010). *Technology and engineering literacy assessment and item specifications for the 2014 National Assessment of Educational Progress - Pre-publication edition*. Washington DC: National Assessment Governing Board.

National Assessment Program. (2016a). ICT literacy. Retrieved from *https://www.nap.edu.au/nap-sample-assessments/ict-literacy*

National Assessment Program. (2016b). Science literacy. Retrieved from *https://www.nap.edu.au/nap-sample-assessments/science-literacy*

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

National Research Council. (1996). *National science education standards*. Washington DC: National Academy of Sciences.

National Research Council, Board on Testing and Assessment, & Committee on the Assessment of 21st Century Skills. (2016). *Assessing 21st century skills*. In J. A. Koenig (Ed.).

Northern Territory Government. (2018). *STEM in the territory strategy 2018-2022*. Retrieved from *https://education.nt.gov.au/__data/assets/pdf_file/0011/591950/STEM-Territory-18-22-web.pdf*

Norton, A. (2016). The number of science graduates are growing but the jobs are not [Press release]. Retrieved from *https://grattan.edu.au/the-number-of-science-graduates-are-growing-but-the-jobs-are-not/*

Office of the Chief Scientist. (2012). Mathematics, engineering & science in the national interest. Retrieved from *https://www.chiefscientist.gov.au/sites/default/files/Office-of-the-Chief-Scientist-MES-Report-8-May-20121.pdf*

Office of the Chief Scientist. (2013a). *Science, technology, engineering and mathematics in the national interest: A strategic approach*. Retrieved from *https://www.chiefscientist.gov.au/sites/default/files/STEMstrategy290713FINALweb.pdf*

Office of the Chief Scientist. (2013b). *STEM: Country comparisons. Report by the Australian Council of Learned Academies for PMSEIC*. Retrieved from Office of the Chief Scientist: *https://acola.org.au/wp/PDF/SAF02Consultants/SAF02_STEM_%20FINAL.pdf*

Office of the Chief Scientist. (2014a). *Benchmarking Australian science, technology, engineering and mathematics*. Retrieved from *https://www.chiefscientist.gov.au/sites/default/files/BenchmarkingAustralianSTEM_Web_Nov2014.pdf*

Office of the Chief Scientist. (2014b). *Science, technology, engineering and mathematics: Australia's future*. Retrieved from *https://www.chiefscientist.gov.au/sites/default/files/STEM_AustraliasFuture_Sept2014_Web.pdf*

Office of the Chief Scientist. (2017). *Science and maths in Australian secondary schools*. Retrieved from *https://www.chiefscientist.gov.au/sites/default/files/OCS-Datasheet-secondary-schools_WEB-VERSION.pdf*

Ohidy, A. (2008). *Lifelong learning: Interpretations of an education policy in Europe*. Germany: VS Research.

Organisation for Economic Co-operation and Development. (2000). *Measuring student knowledge and skills, the PISA 2000 assessment of reading, mathematical and scientific literacy*. Retrieved from *http://www.oecd.org/education/school/programmeforinternationalstudentassessmentpisa/33692793.pdf*

Organisation for Economic Co-operation and Development. (2003a). *The PISA 2003 assessment framework - Mathematics, reading, science and problem solving knowledge and skills*. Retrieved from *http://www.oecd.org/education/school/programmeforinternationalstudentassessmentpisa/33694881.pdf*

Organisation for Economic Co-operation and Development. (2003b). *Scientific literacy: The PISA 2003 assessment framework*. Paris: Author.

Organisation for Economic Co-operation and Development. (2006). *Assessing scientific, reading and mathematical literacy - A framework for PISA 2006*. Retrieved from *https://www.oecd-ilibrary.org/education/assessing-scientific-reading-and-mathematical-literacy_9789264026407-en*

Organisation for Economic Co-operation and Development. (2009). *PISA 2009 assessment framework key competencies in reading, mathematics and science*. Retrieved from *https://www.oecd.org/pisa/pisaproducts/44455820.pdf*

Organisation for Economic Co-operation and Development. (2010). *The high cost of low educational performance: The long-run economic impact of improving PISA outcomes*. Retrieved from *https://www.oecd.org/pisa/44417824.pdf*

Organisation for Economic Co-operation and Development. (2012). *PISA 2012 assessment and analytical framework mathematics, reading, science, problem solving and financial literacy*. Retrieved from *https://www.oecd.org/pisa/pisaproducts/PISA%202012%20framework%20e-book_final.pdf*

Organisation for Economic Co-operation and Development. (2014). *Reviews of national policies for education: Secondary education in Kazakhstan*. Retrieved from *https://books.google.com.au/books?id=3t2iAgAAQBAJ&pg=PA38&lpg=PA38&dq=kazakhstan+timss+pisa+shock&source=bl&ots=31pJknQsrC&sig=hbCqPIF3696voV5DbWXG3I9rYFo&hl=en&sa=X&ved=0ahUKEwjHyIj7gNXQAhUBqJQKHZc9D1IQ6AEIJTAB#v=onepage&q=kazakhstan%20timss%20pisa%20shock&f=false*

Organisation for Economic Co-operation and Development. (2016). About PISA. Retrieved from *https://www.oecd.org/pisa/aboutpisa/*

Organisation for Economic Co-operation and Development. (2017). *PISA 2015 assessment and analytical framework: Science, reading, mathematic, financial literacy and collaborative problem solving, revised edition*. Retrieved from Paris: *http://www.oecd-ilibrary.org/education/pisa-2015-assessment-and-analytical-framework/pisa-2015-background-questionnaires_9789264255425-8-en*

Organisation for Economic Co-operation and Development. (2018). *PISA for Development assessment and analytical framework: Reading, mathematics and science*. Retrieved from *https://www.oecd-ilibrary.org/search?value1=PISA+assessment+framework&option1=quicksearch&facetOptions=51&facetNames=pub_igoId_facet&operator51=AND&option51=pub_igoId_facet&value51=%27igo%2Foecd%27&publisherId=%2Fcontent%2Figo%2Foecd*

Panizzon, D., Corrigan, D., Forgasz, H., & Hopkins, S. (2015). Impending STEM shortages in Australia: Beware the 'Smoke and Mirrors'. *Procedia - Social and Behavioural Sciences, 167*, 70-74.

Peters-Burton, E. E. (2014). Is there a "Nature of STEM"? *School Science and Mathematics, 114*(3), 99-101.

Prinsley, R., & Baranyai, K. (2015). *STEM skills in the workforce: What do employers want?* Retrieved from *http://www.chiefscientist.gov.au/wp-content/uploads/OPS09_02Mar2015_Web.pdf*

Redman, C. (2017). Would increasing engineering literacies enable untapped opportunities for STEM education? *Theory into Practice, 56*, 318-326.

Riddle, S. (2015). Teachers learn over many years in the job - not just at university. *The Conversation*. Retrieved from *https://theconversation.com/teachers-learn-over-many-years-in-the-job-not-just-at-university-39486*

Rindermann, H., & Baumeister, A. E. E. (2015). Validating the interpretations of PISA and TIMSS tasks: A rating study. *International Journal of Testing, 15*(1), 1-22.

Roehl, T. (2015). What PISA measures: some remarks on standardized assessment and science education. *Cultural Studies of Science Education, 10*, 1215-1222.

Saldana, J. (2016). *The coding manual for qualitative researchers* (3rd ed.). Los Angeles: SAGE Publications Ltd.

Salzman, H., & Benderley, B. L. (2019). STEM performance and supply: Assessing the evidence for education policy. *Journal of Science Education and Technology, 28*, 9-25.

Salzman, H., Kuehn, D., & Lowell, B. L. (2013). *Guestworkers in the high-skills U.S. labor market*. Retrieved from *https://www.epi.org/publication/bp359-guestworkers-high-skill-labor-market-analysis/*

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher, 68*(4), 20-26.

Schleicher, A. (2019). *PISA 2018 insights and interpretations*. Retrieved from *https://www.oecd.org/pisa/PISA%202018%20Insights%20and%20Interpretations%20FINAL%20PDF.pdf*

Science & Technology Australia. (2018). STEM qualified teachers will provide spark, but unis need investment to ignite Australia's future. Retrieved from *https://scienceandtechnologyaustralia.org.au/stem-qualified-teachers-will-provide-spark-but-unis-need-investment-to-ignite-australias-future/*

Scutt, D. (2018). Australia is actually producing less STEM graduates now than it was 10 years ago. *Business Insder Australia*. Retrieved from *https://www.businessinsider.com.au/australia-skill-shortages-stem-study-fields-2018-11*

Siekmann, G., & Korbel, P. (2016). *Defining "STEM" skills: review and synthesis of the literature - support document 1*. Retrieved from Adelaide: *https://www.ncver.edu.au/__data/assets/pdf_file/0022/61339/Support-doc-1-Defining-STEM-skills-review-and-synthesis-of-the-literature.pdf*

Singhal, P. (2018). Teaching to NAPLAN leading to Australia's falling PISA scores: expert. *The Sydney Morning Herald*. Retrieved from *https://www.smh.com.au/education/teaching-to-naplan-leading-to-australia-s-falling-pisa-scores-expert-20180510-p4zeg5.html*

Sjoberg, S. (2012). PISA: Politics, fundamental problems and intriguing results. *La Revue, Recherces en Education*(14), 1-21. Retrieved from *http://www.scienceinpublic.com.au/wp-content/uploads/Svein-Sjoberg-PISA-tests_La-Revue_no14-Sept-2012.pdf*

Sjostrom, J. (2017, August 2017). *Vision III: Framing STEM education with moral-philosophical-existential-political alternatives*. Paper presented at the ESERA Dublin.

Smith, A. (2018). STEM has become a buzzword and a fad: NSW education minister. *The Sydney Morning Herald*. Retrieved from *https://www.smh.com.au/politics/nsw/stem-has-become-a-buzzword-and-a-fad-nsw-education-minister-20180321-p4z5iw.html*

Smith, C., & Watson, J. (2016). *STEM education and education for sustainability (EFS): Finding common ground for a flourishing future*. Paper presented at the Australian Association for Research in Education, Melbourne. *https://www.aare.edu.au/data/2016_Conference/Full_papers/547_Caroline_Smith.pdf*

Smith, E., & White, P. (2019). Where do all the STEM graduates go? Higher education, the labour market and career trajectories in the UK. *Journal of Science Education and Technology, 28*, 26-40.

Soriano, F., & Abello, R. (2015). Modelling the relationships between the use of STEM skills, collaboration, R&D, and innovation among Australian businesses. *Australian Journal of Labour Economics, 18*(3), 345-374.

Sowey, M. (2018). The test that fails: The NAPLAN persausive writing test subverts critical thinking. *The Australian Rationalist, 110*(Sep), 13-14.

Stroud, G. (2017, 6 February 2017). Why do teachers leave?, Opinion. *ABC News*. Retrieved from *http://www.abc.net.au/news/2017-02-04/why-do-teachers-leave/8234054*

Teachers have lost faith in NAPLAN. (2019). *Guardian* p. 4.

Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. *American Journal of Evaluation*(June), 237-246.

Thomson, A. M., Perry, J. L., & Miller, T. K. M. (2007). Conceptualising and measuring collaboration. *Journal of Public Administration Research and Theory, 19*, 23-56.

Thomson, S. (2016). Australian schools continue to fall behind other countries in maths and science. Retrieved from *http://theconversation.com/australian-schools-continue-to-fall-behind-other-countries-in-maths-and-science-69341*

Thomson, S., Cresswell, J., & De Bortoli, L. (2004). *Facing the future: A focus on mathematical literacy among Australian 15-year-old students in PISA 2003*. Retrieved from *https://research.acer.edu.au/ozpisa/3/*

Thomson, S., & De Bortoli, L. (2008). *Exploring scientific literacy: How Australia measures up: The PISA 2006 survey of students' scientific, reading and mathematical literacy skills*. Retrieved from Camberwell: *https://research.acer.edu.au/ozpisa/2/*

Thomson, S., De Bortoli, L., & Buckley, S. (2013). *PISA 2012: how Australia measures up*. Retrieved from *https://research.acer.edu.au/cgi/viewcontent.cgi?article=1015&context=ozpisa*

Thomson, S., De Bortoli, L., Nicholas, M., Hillman, K., & Buckley, S. (2011). *Challenges for Australian education: Results from PISA 2009: The PISA 2009 assessent of students' reading, mathematical and scientific literacy*. Retrieved from Camberwell: *https://www.acer.org/files/PISA-Report-2009.pdf*

Thomson, S., De Bortoli, L., & Underwood, C. (2016). *PISA 2015: A first look at Australia's results*. Retrieved from *http://research.acer.edu.au/cgi/viewcontent.cgi?article=1021&context=ozpisa*

Thomson, S., De Bortoli, L., & Underwood, C. (2017). *PISA 2015: Reporting Australia's results*. Retrieved from *https://research.acer.edu.au/cgi/viewcontent.cgi?article=1023&context=ozpisa*

Thomson, S., Wernert, N., O'Grady, E., & Rodrigues, S. (2016). *TIMSS 2015: A first look at Australia's results*. Retrieved from *http://research.acer.edu.au/cgi/viewcontent.cgi?article=1000&context=timss_2015*

Timms, M., Moyle, K., Weldon, P., & Mitchell, P. (2018). *Challenges in STEM Learning in Australian Schools*. Retrieved from *https://research.acer.edu.au/cgi/viewcontent.cgi?article=1028&context=policy_analysis_misc*

Tonkin, C. (2019). The tech talent shortage is real - Businesses want a very particular set of skills. *Information Age*. Retrieved from *https://ia.acs.org.au/article/2019/the-tech-talent-shortage-is-real.html*

United Nations Educational, Scientific and Cultural Organization,. (2012). *Youth and skills: Putting education to work*. Retrieved from

van den Hurk, A., Meelissen, M., & van Langen, A. (2019). Interventions in education to prevent STEM pipeline leakage. *International Journal of Science Education, 41*(2), 150-164.

Waite, A. M., & McDonald, K. S. (2019). Exploring challenges and solutions facing STEM careers in the 21st century: A human resource development perspective. *Advances in Developing Human Resources, 21*(1), 3-15.

Waters, L. (2016). Teaching wellbeing at school. Retrieved from *https://pursuit.unimelb.edu.au/articles/teaching-wellbeing-at-school*

Watt, C. (2019). What is NAPLAN's future? *Independent Education, 49*(2), 16-17.

Yore, L. D., Pimm, D., & Tuan, H.-L. (2007). The literacy component of mathematical and scientific literacy. *International Journal of Science Education, 5*(4), 559-589.

Youth Insight. (2019). *Youth in STEM research: Summary of results*. Retrieved from *https://www.industry.gov.au/sites/default/files/2019-03/youth-in-stem-research-2019-summary-results.pdf*

Zhao, Y. (2019). The rise of the useless: the case for talent diversity. *Journal of Science Education and Technology, 28*(1), 62-68.

Zimmerman, B. J., Bonner, S., & Kovach, R. (1996). Developing self-regulated learners: Beyond achievement to self-efficacy. In *Psychology in the classroom: A series on applied educational psychology* (pp. 25-46). Washington DC: American Psychological Association.

Zollman, A. (2012). Learning for STEM literacy: STEM literacy for learning. *School Science and Mathematics, 112*(1), 12-19.

Appendix A

Survey Instrument

Complete questionnaire

The complete questionnaire is presented below. It therefore also includes questions that were not ultimately used in this research. Following the questionnaire is an outline of which questions were analysed within Sections 1 to 4, as discussed in this thesis. Appendix A concludes with a brief overview of the purpose of the other questions which will be used as the basis for subsequent research.

Participant Information Sheet

Researcher:
This project is the work of Jennifer Colley, a PhD candidate in science communication, under the supervision of Professor Sue Stocklmayer at the Australian Centre for the Public Awareness of Science (CPAS) at the Australian National University.

Project Title: STEM Skills in Australian High Schools.

General Outline of the Project:
Description and Methodology: This aim of this project is to determine the extent to which science, technology, engineering and mathematics (STEM) skills are developed and assessed within Year 7-10 STEM subjects across Australia. Data collection is via an online survey.
Participants: The survey will be distributed to teachers of Year 7-10 STEM subjects in Australia. Please feel free to distribute the survey to other Australian teachers of Year 7-10 STEM subjects. Responses from at least 200 participants are sought but more are welcome.
Use of Data and Feedback: The results of this survey will be collated and analysed in the form of a PhD thesis set for completion in December 2018 as well as possible academic publications. A summary of the research will be posted to http://diffusion.weblogs.anu.edu.au/ and made available to professional organisations who took part.

Participant Involvement:
- **Voluntary Participation & Withdrawal: Participation in this project is voluntary and by commencing the questionnaire you are agreeing to take part. You can decline to take part, withdraw from the research or choose not to answer questions without providing an explanation. As survey responses will not be identifiable by name, withdrawal must take place before submitting the survey to ensure that data will not be included in the research.**
- **Participation involves the completion of this online survey.**
- **Location and Duration: The study will take place via an online SurveyMonkey questionnaire. It should take 20-30 minutes to complete.**
- **Risks: The survey focuses on the extent to which you feel you develop and assess a range of STEM skills in a particular subject. There are also some questions concerning the Australian Curriculum and the approach taken to teaching STEM subjects at your school. If any of the questions cause you discomfort you may withdraw from the survey at any time before completing it.**
- **Benefits: This research is expected to help gain insights into the development and assessment of STEM skills within Australian high schools. This is with a view to proposing means of better supporting teachers and schools in cultivating STEM skills within their students.**

Exclusion criteria:
- **Participant Limitation: Survey participants must be practising teachers within an Australian school and teach at least one Year 7, 8, 9 or 10 (or mixed year level within this year bracket) STEM subject. For the purposes of this survey, a STEM subject may be a stand-alone disciplinary subject, such as science or mathematics, or an integrated STEM subject. Essentially any subject which calls on at least one of the four STEM disciplines is acceptable.**

Confidentiality:
- **While your name will remain anonymous, you will be asked to provide information about your school so that demographics can be taken into account and to enable a possible invitation to your school to participate in any follow-up research. Your individual responses will only be visible to the researcher, thus no one at your school or within your educational department will be able to identify you from your responses. Confidentiality will be protected as far as the law allows.**

Should any of your responses be used in published material it will be done under a pseudonym or with no attribution.

Privacy Notice:
In collecting your personal information within this research, the ANU must comply with the Privacy Act 1988. The ANU Privacy Policy is available at https://policies.anu.edu.au/ppl/document/ANUP_010007 and it contains information about how a person can:

- Access or seek correction to their personal information;
- Complain about a breach of an Australian Privacy Principle by ANU, and how ANU will handle the complaint.

Data Storage:

- Where: Data will be stored on a password-protected computer with secure back up or in a locked cabinet.
- How long: Data will be stored for a period of at least five years from the publication of any material arising from the research.
- Handling of Data following the required storage period: Following this five year period, the data will be deleted.

Queries and Concerns:

- Contact Details for More Information: For more information or queries regarding the study please contact the primary investigator, Jennifer Colley (+61 2 6125 0498, jennifer.colley@anu.edu.au) or her supervisor Sue Stocklmayer (+61 2 6125 8157, sue.stocklmayer@anu.edu.au) at the Australian National Centre for the Public Awareness of Science.

Ethics Committee Clearance:
The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee (Protocol 2017/277). If you have any concerns or complaints about how this research has been conducted, please contact:
Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: +61 2 6125 3427
Email: Human.Ethics.Officer@anu.edu.au

1. I have read and understood the information above about this research project and I have had any questions or concerns about the project addressed to my satisfaction.
I understand that participation is voluntary and that I may withdraw from the survey at any time prior to its submission without explanation or any repercussion.
I understand that this research may be published in a doctoral thesis, associated publications and that summaries of the research will be provided to education departments across Australia (Government, Catholic and Independent sectors) as well as professional organisations who assisted in disseminating the survey for publication on their sites should they choose and that participants and schools will not be identified in any way.
I consent to participate in this research.

◯ Yes

◯ No

Information about you

This page has some questions about you, your qualifications, teaching experiences and school environment.

2. Are you female or male?

- ◯ Female
- ◯ Male

3. How old are you?

- ◯ Under 25
- ◯ 25-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50-59
- ◯ 60 or more

4. What year did you start teaching?

5. At the end of this school year, how many years will you have taught altogether (either full or part time)? Please round to the nearest whole number.

6. What is the highest level of formal education you have attained?

- ◯ Bachelor Degree
- ◯ Graduate Diploma
- ◯ Masters Degree
- ◯ PhD
- ◯ Other (please specify)

7. What is the highest level of formal education you have completed which included subjects in science and/or technology and/or engineering and/or mathematics?

- ◯ Bachelor's degree
- ◯ Graduate Diploma
- ◯ Master's degree
- ◯ PhD
- ◯ Other (please specify)

8. In which of the following STEM areas have you completed university-level subjects? Select as many are applicable.

- ☐ Science
- ☐ Technology (digital)
- ☐ Technology (design)
- ☐ Engineering
- ☐ Mathematics
- ☐ Statistics
- ☐ None of the above. Please enter the subjects you have studied which are most closely aligned with STEM.

9. Do you consider yourself to be teaching in or out of area for any STEM subjects you are currently teaching.

- ◯ In area
- ◯ Out of area
- ◯ Other (please specify)

10. With which area/s of STEM do you feel most strongly aligned on the basis of your qualifications and/or experience. Select as many as are applicable.

- ☐ Science
- ☐ Technology
- ☐ Engineering
- ☐ Mathematics

11. In which state or territory of Australia do you currently teach?

- ◯ Australian Capital Territory
- ◯ New South Wales
- ◯ Northern Territory
- ◯ Queensland
- ◯ South Australia
- ◯ Victoria
- ◯ Western Australia
- ◯ Tasmania

12. What is the location (city/town) and postcode of the school at which you currently teach?

Location

Postcode

13. What is the name of your school? Please note that the researcher may follow-up with your school to invite them to participate in further research. You may leave this question blank if you wish.

14. What is the sector of your school?

- ◯ Government
- ◯ Catholic
- ◯ Independent
- ◯ Other (please specify)

15. Which of the following best describes your school? (Focus on gender break-down in Years 7-10)

- ◯ Coeducational
- ◯ Girls only
- ◯ Boys only
- ◯ Other (please specify)

Your perceptions of STEM skills

"STEM skills" are currently of great focus in education and the workforce, both within Australia and internationally. However, whilst STEM skills are often cited as being desirable within graduates and employees, they are rarely defined.
This page is designed to illicit information on your perceptions of STEM skills.

16. Have you heard the phrase "STEM skills" prior to this survey?

- ◯ Yes
- ◯ No
- ◯ Not sure

17. If you have heard the phrase "STEM skills" prior to this survey, where have you heard it? Select as many as are applicable.

- ☐ News
- ☐ Media
- ☐ Office of Chief Scientist publications
- ☐ Professional development
- ☐ Professional associations
- ☐ Syllabus or curriculum documents
- ☐ Colleagues
- ☐ Other (please specify)

18. Regardless of whether you've heard the phrase before, what skills do you think of when you hear the phrase "STEM skills"?
Please list 5 to 10 skills.

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.

Development and Assessment of STEM skills in schools

For the purpose of the rest of this survey, a selection of skills have been chosen for you to reflect upon. They fall under five broad categories which you will be asked about one at a time.

Skills are developed to different extents within different contexts and so you are asked to select a Year 7-10 subject you are currently teaching, or have taught in the last year, and to answer the remaining questions of this survey with that subject in mind. You are encouraged to select the subject you think would develop STEM skills most strongly.

You will be asked about the extent to which you provide opportunities for students todevelop and range of skills - this means the extent to which formal and/or informal opportunities have been provided for students to practise and improve that particular skill.

You will also be asked about the extent to which youassess each of these skills - this assessment may be formal or informal but must be part of a process in which evidence is gathered which provides insights into student skill levels.

19. What is the disciplinary area of the subject you will keep in mind for answering the questions which remain in this survey?

- ◯ Science
- ◯ Digital Technology
- ◯ Design Technology
- ◯ Mathematics
- ◯ Other (for example, if you have taught a STEM-specific subject or an integrated unit which covers multiple disciplinary areas, please briefly describe it).

20. What is the year level of the subject you will keep in mind for answering the questions which remain in this survey?

- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10
- ◯ Other, e.g. mixed year level (please specify, it must involve 7/8/9/10 students)

Literacy Skills

For the purposes of the questions on this page, please use the following definitions:

Skill	Definition
Scientific Literacy	**The ability to use scientific concepts and processes in explaining phenomena and interpreting data and evidence when making personal and collective decisions.**
Technological Literacy	**The ability to use, understand and evaluate technology, use technological principles to develop solutions and recognise that society and technology shape one another.**
Engineering Literacy	**The ability to apply mathematical and scientific principles to design, manufacture and operate efficient and economical systems for the benefit of society.**
Mathematical Literacy	**The ability to utilise mathematics to solve problems and make decisions within the context of private, occupational and social life and as a reflective citizen.**
STEM Literacy	**The integration of skills, abilities, knowledge and disciplinary practices of science, technology, engineering and mathematics, to enable the creation of innovative solutions to complex problems.**

21. Within your chosen subject, to what extent do you provide opportunities for students to develop each of the following literacy skills?

	Not at all	Small	Moderate	Large	Very large
Scientific Literacy	○	○	○	○	○
Technological Literacy	○	○	○	○	○
Engineering Literacy	○	○	○	○	○
Mathematical Literacy	○	○	○	○	○
STEM Literacy	○	○	○	○	○

Optional comment

22. Within your chosen subject, to what extent do you assess each of the following literacy areas?

	Not at all	Small	Moderate	Large	Very large
Scientific Literacy	○	○	○	○	○
Technological Literacy	○	○	○	○	○
Engineering Literacy	○	○	○	○	○
Mathematical Literacy	○	○	○	○	○
STEM Literacy	○	○	○	○	○

Optional comment

Disciplinary Skills

For the purposes of the questions on this page, please use the following definitions:

Skill	Definition
Mathematical	The ability to choose the right mathematical methods or formulas to solve a problem as well as the ability to perform mathematical operations quickly and accurately.
Scientific	Using scientific rules and methods (such as forming hypotheses and collecting and analysing data) to solve problems.
Programming	Writing computer programs for various purposes.
Design thinking	Processes of inquiry and learning performed in a systems context involving tolerance of ambiguity and uncertainty, decision-making, collaboration and communication in the myriad of design languages.
Operations analysis	Analysing needs and product requirements to create a design.
Technology design	Generating or adapting equipment and technology to serve user needs.
Systems analysis and evaluation	Determining how a system should work and how changes in conditions, operations, and the environment will affect outcomes as well as the actions needed to improve or correct performance, relative to the goals of the system.

23. Within your chosen subject, to what extent do you provide opportunities for students to develop each of the following disciplinary skills?

	Not at all	Small	Moderate	Large	Very large
Mathematical	○	○	○	○	○
Scientific	○	○	○	○	○
Programming	○	○	○	○	○
Design thinking	○	○	○	○	○
Operations analysis	○	○	○	○	○
Technology design	○	○	○	○	○
Systems analysis and evaluation	○	○	○	○	○

Optional comment

24. Within your chosen subject, to what extent do you assess each of the following disciplinary skills?

	Not at all	Small	Moderate	Large	Very large
Mathematical	◯	◯	◯	◯	◯
Scientific	◯	◯	◯	◯	◯
Programming	◯	◯	◯	◯	◯
Design thinking	◯	◯	◯	◯	◯
Operations analysis	◯	◯	◯	◯	◯
Technology design	◯	◯	◯	◯	◯
Systems analysis and evaluation	◯	◯	◯	◯	◯

Optional comment

Higher Order Thinking Skills

For the purposes of the questions on this page, please use the following definitions:

Skill	Definition
Deductive reasoning	**The ability to apply general rules to specific problems.**
Inductive reasoning	**The ability to combine pieces of information to form general rules or conclusions (includes finding a relationship among seemingly unrelated events).**
Active learning	**Understanding the implications of new information for both current and future problem-solving and decision making.**
Critical thinking	**Using logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions, or approaches to problems.**
Complex problem solving	**Identifying complex problems and reviewing related information to develop and evaluate options and implement solutions.**
Creative problem solving	**Characterised by divergent thinking (generation of a variety of ideas) and relational reasoning (the ability to identify meaningful patterns) by way of generating a wide variety of original ideas.**

25. Within your chosen subject, to what extent do you provide opportunities for students to develop each of the following higher order thinking skills?

	Not at all	Small	Moderate	Large	Very large
Deductive reasoning	○	○	○	○	○
Inductive reasoning	○	○	○	○	○
Active learning	○	○	○	○	○
Critical thinking	○	○	○	○	○
Complex problem solving	○	○	○	○	○
Creative problem solving	○	○	○	○	○

Optional comment

26. Within your chosen subject, to what extent do you assess each of the following higher order thinking skills?

	Not at all	Small	Moderate	Large	Very large
Deductive reasoning	◯	◯	◯	◯	◯
Inductive reasoning	◯	◯	◯	◯	◯
Active learning	◯	◯	◯	◯	◯
Critical thinking	◯	◯	◯	◯	◯
Complex problem solving	◯	◯	◯	◯	◯
Creative problem solving	◯	◯	◯	◯	◯

Optional comment

Interpersonal Skills

For the purposes of the questions on this page, please use the following definitions:

Skill	Definition
Communication	**The ability to be able to effectively engage in and exchange ideas, involving the use of appropriate language and conventions for a given context/audience and selection and mastery of an appropriate medium.**
Team participation and collaboration	**The ability to effectively work towards a common goal within a team which has well defined roles and responsibilities for its members with the collaboration expected to lead to mutual benefits by the achievement of a common goal.**

27. Within your chosen subject, to what extent do you provide opportunities for students to develop each of the following interpersonal skills?

	Not at all	Small	Moderate	Large	Very large
Communication	○	○	○	○	○
Team participation and collaboration	○	○	○	○	○

Optional comment

28. Within your chosen subject, to what extent do you assess each of the following interpersonal skills?

	Not at all	Small	Moderate	Large	Very large
Communication	○	○	○	○	○
Team participation and collaboration	○	○	○	○	○

Optional Comment

Intrapersonal skills

For the purposes of the questions on this page, please use the following definitions:

Skill	Definition
Lifelong learning	**Development of a love of learning and an awareness of the most personally effective learning strategies to enable continued learning in different contexts throughout life.**
Self-motivation, initiative and the ability to work independently	**The ability to set goals, identify and utilise required resources and apply personally effective strategies to obtain the desired outcomes, motivating one's self as required, particularly when faced with difficult and/or boring tasks.**
Time management	**The ability to self-regulate and self-monitor the use of one's time by setting realistic goals, prioritising tasks and self-rewarding success.**

29. Within your chosen subject, to what extent do you provide opportunities for students to develop each of the following intrapersonal skills?

	Not at all	Small	Moderate	Large	Very large
Lifelong learning	○	○	○	○	○
Self-motivation, initiative and the ability to work independently	○	○	○	○	○
Time management	○	○	○	○	○

Optional comment

30. Within your chosen subject, to what extent do you assess each of the following intrapersonal skills?

	Not at all	Small	Moderate	Large	Very large
Lifelong learning	○	○	○	○	○
Self-motivation, initiative and the ability to work independently	○	○	○	○	○
Time management	○	○	○	○	○

Optional comment

The Australian Curriculum

This page is focused upon the Australian Curriculum. If your chosen subject is not aligned with the Australian Curriculum, you may proceed to the next section.

For Q28, the skills presented within the survey have been listed again for your reference:

- **Scientific Literacy**
- **Technological Literacy**
- **Engineering Literacy**
- **Mathematical Literacy**
- **STEM Literacy**
- **Mathematical**
- **Scientific**
- **Programming**
- **Design thinking**
- **Operations analysis**
- **Technology design**
- **Deductive reasoning**
- **Inductive reasoning**
- **Active learning**
- **Critical thinking**
- **Complex problem solving**
- **Creative problem solving**
- **Communication**
- **Team participation and collaboration**
- **Lifelong learning**
- **Self-motivation, initiative and the ability to work independently**
- **Time management**

31. If your chosen subject is aligned with the Australian Curriculum, to what extent do you feel the Australian Curriculum supports the development of the skills described in this survey?

32. If your chosen subject is aligned with the Australian Curriculum, to what extent are you familiar with the following aspects of the Australian Curriculum?

	Not at all	Small	Moderate	Large	Very large
Learning Area Rationale	◯	◯	◯	◯	◯
Learning Area Aims	◯	◯	◯	◯	◯
Learning Area Key ideas	◯	◯	◯	◯	◯
Learning Area Structure	◯	◯	◯	◯	◯
The General Capabilities	◯	◯	◯	◯	◯
The Cross-Curriculum Priorities	◯	◯	◯	◯	◯
The Scope and Sequence across multiple year levels	◯	◯	◯	◯	◯
Year Level Content Descriptions	◯	◯	◯	◯	◯
Year Level Elaborations	◯	◯	◯	◯	◯
Year Level Achievement Standards	◯	◯	◯	◯	◯
Year Level Work Samples	◯	◯	◯	◯	◯

Optional comment

Models of STEM

The question on this page is in regard to how STEM is implemented within your school.

33. Which of the following best describes the model of STEM utilised by your school?

- ◯ No particular focus on STEM, subjects are taught separately.
- ◯ STEM subjects are taught separately by subject specialists though teachers collaborate and plan together so that concepts taught in one STEM subject can be applied within another.
- ◯ STEM subjects are not taught separately but are instead clustered in a new course which integrates the disciplines and is focused on problem-based and/or inquiry learning.
- ◯ STEM subjects are taught separately by subject specialists but students have regular time to work in small teams to integrate their learning and develop their ideas in a problem-based environment through completing a central project (designed by the teacher) which calls on content and skills from each discipline.
- ◯ STEM subjects are taught separately by subject specialists but students have regular time to work in small teams to integrate their learning and develop their ideas in a problem-based environment through completing a central project (designed by the students) which calls on content and skills from each discipline.
- ◯ A highly individualised approach in which students design their own projects which are then mapped back to learning outcomes from STEM (and possibly other) subject curriculum/syllabus documents.
- ◯ Other (please explain)

Final Thoughts

This page allows you to make some brief comments about the development and assessment of the skills presented within this survey. To help in answering them, the skills have been listed again below:

- **Scientific Literacy**
- **Technological Literacy**
- **Engineering Literacy**
- **Mathematical Literacy**
- **STEM Literacy**
- **Mathematical**
- **Scientific**
- **Programming**
- **Design thinking**
- **Operations analysis**
- **Technology design**
- **Deductive reasoning**
- **Inductive reasoning**
- **Active learning**
- **Critical thinking**
- **Complex problem solving**
- **Creative problem solving**
- **Communication**
- **Team participation and collaboration**
- **Lifelong learning**
- **Self-motivation, initiative and the ability to work independently**
- **Time management**

You will be asked whether you have experienced any particular successes and/or challenges in the development/assessment of these skills. These may be related to the structure of your course, the practicalities of its implementation, your students etc.

34. Within your chosen subject, describe some successes you've experienced the the development of one or two of these skills.

35. Within your chosen subject, describe some challenges you've experienced in the development of one or two of these skills.

36. Within your chosen subject, describe some successes you've experienced in the assessment of one or two of these skills.

37. Within your chosen subject, describe some challenges you've experienced in assessing one or two of these skills.

The end

Thank you very much for your participation in this survey. If you have any other further comments, please leave them in the space below, otherwise click 'Done' to finish.

38. Is there anything you would like to add?

Mapping of Questions to Sections

Table 28 shows which questions from the questionnaire were categorised into Sections 1 to 4 as analysed in this thesis.

Table 28 – Questions from the questionnaire used within each section as analysed within the thesis

Section	**Questions**
1	2, 3, 5, 6, 9, 11, 14
2	16, 17
3	18
4	31, 31

The questions from the questionnaire that were omitted from analysis in this thesis but which were collected at the same time are listed in Table 29 with an explanation as to why they were included in the questionnaire but omitted from analysis in this study.

Table 29 – Questions omitted from the questionnaire omitted from analysis in this study and why

Questions	Explanation
4, 7, 8, 10	These questions sought to gain more information about the respondents and their education and teaching experience. An insufficient sample size was gathered for analysis to be done on this basis.
12, 13, 14	Questions 12 and 13 were asked as there was a potential to do a follow-up study involving participants in the survey. The issues encountered in gaining permission from states/territories and sectors to get teachers to complete an online survey in their own time indicated that the difficulty in conducting a representative focus group would be very high. Additionally, the scope of the study was sufficiently large already to warrant this to be unnecessary.
15	This question sought additional information regarding the demographics of the schools of the participants with respect to gender break-down of the students. This was done because there is a large focus on girls within STEM. However, again, sample size was insufficient to justify breakdown on this basis and also went beyond the scope of the study.
19 – 30, 34 – 37	These sections of the questionnaire were included to obtain data for a component of the study which was eventually omitted as the scope of the study was becoming too large. Teachers were asked to select a specific subject and year level to focus on when asked about the extent to which they felt they were developing and assessing the skills identified from the literature in Chapter 5 Part 1. In the second set of questions teachers were asked about successes and challenges they had experienced in developing and assessing these skills. This was so that successes could be shared and challenges could be made known to a wider audience.
33	The original intention was to also so investigate the models of STEM being used in schools in Australia. Again, this ultimately broadened the study too much and will be investigated separately.
38	Very few responses and pertained predominantly to the aspects of the study outlined above which were ultimately not analysed.

Appendix B

Example of letter to the Principal requesting permission for teacher participation

Different states and territories and different sectors had their own processes for gaining approval. In some instances, no approval was needed, and so teachers could complete the survey via Facebook or Twitter. In some jurisdictions, approval needed to be provided by the governing body for the particular state/territory. In some instances that involved a letter, in others they had their own application document which needed to be completed. For some jurisdictions and for the Independent sector, Principals were contacted directly. For jurisdictions requiring prior top-level approval, a sentence indicating that the approval had been given by the relevant body was included. However, all forms of contact were predominantly the same and the vast majority of these involved a letter to the Principal with a consent form. An example of this has been provided on the next two pages.

National Centre for the Public Awareness of Science
The Australian National University
Peter Baume Building #42A
Linnaeus Way
Acton ACT 2601
Australia
jennifer.colley@anu.edu.au
0400497170

To the Principal

My name is Jennifer Colley and I am writing to you regarding research I am conducting as part of my PhD at the National Centre for the Public Awareness of Science at the Australian National University. This research is being conducted under the supervision of Professor Sue Stocklmayer AO and seeks to determine the extent to which science, technology, engineering and mathematics (STEM) skills are developed and assessed in Australian High Schools.

Over the past few years there has been an increasing focus on STEM at the educational, workforce and government level in Australia and around the world. The increased focus on STEM is largely in response to research which indicates that the current growth rate of STEM jobs is substantially higher than that of other jobs. A range of STEM skills have been identified by employers, both within and beyond STEM fields, that they value in their employees and which are typically found to be more strongly developed in employees with a background in STEM.

My research takes the form of an online survey for teachers of at least one Year 7-10 science, technology (digital or design), engineering, mathematics or integrated STEM subject. It will take approximately 20-30 minutes for teachers to complete the survey at a time convenient to them between now and the end of the 2017 school year. Participation is entirely voluntary.

The research has been approved by the ANU Human Research Ethics Committee. Please note that teachers are asked to provide the name of their school in the survey so that I can ensure that permission for their participation has been granted by you. However, this information will remain completely confidential. No participant, school or sector will be identified in any publication relating to this research. The Independent Schools Council of Australia and the state/territory-level associations, along with participating Departments of Education and Catholic Education Offices across Australia, will be provided with my research findings. You may obtain access to these via the AISNT should you be interested.

By participating in this survey teachers will have the opportunity to highlight successes and challenges they've experienced in the development and assessment of STEM skills. This may then form the basis of future research and professional development opportunities which focus on how to better enable teachers to support their students in the development of these skills. This is to the potential benefit of all students as these skills are desired across the workforce.

If you would like to discuss any aspect of this research you can contact me via the information provided above. If you wish to speak with an independent person about the conduct of the project please contact the Ethics Manager of the ANU Human Research Ethics Committee at *Human.Ethics.Officer@anu.edu.au*, the associated protocol number is 2017/277.

If you are willing for the teachers of your school to participate please complete the Consent Form on the following page, return it to me via email and distribute the survey link *https://www.surveymonkey.com/r/DYP26DZ* to relevant staff at your school.

Thank you for your consideration,
Jennifer Colley

Australian National University

Consent Form

- I have read this document and understand the aims, procedures, and risks of this project, as described within it.
- For any questions I may have had, I have taken up the invitation to ask those questions, and I am satisfied with the answers I received.
- I am willing for teachers at my school to become involved in the research project, as described.
- I understand that participation in the project is entirely voluntarily.
- I understand that the participating teachers are free to withdraw their participation at any time, prior to submission of the survey, without affecting the relationship with the research team or the Australian National University.
- I understand that this research may be published in a doctoral thesis and associated publications as well as in summaries provided to Departments of Education, Catholic Education Offices and Independent Schools Associations across Australia and that neither the participants nor the school or sector will not identified in any way.

Name of School ____________________________

Name of Principal (printed): ____________________________

Signature: ____________________________ Date: / /

Appendix C

Illustrated overview of the Australian Curriculum Website

For those unfamiliar with the Australian Curriculum and wanting more information regarding its layout this appendix provides a tour of the website.

Opening page

The Australian Curriculum website, *https://www.australiancurriculum.edu.au/*, houses all curriculum-related matter for teachers, parents and other stakeholders. Figure 45 shows the top of the opening page of the website.

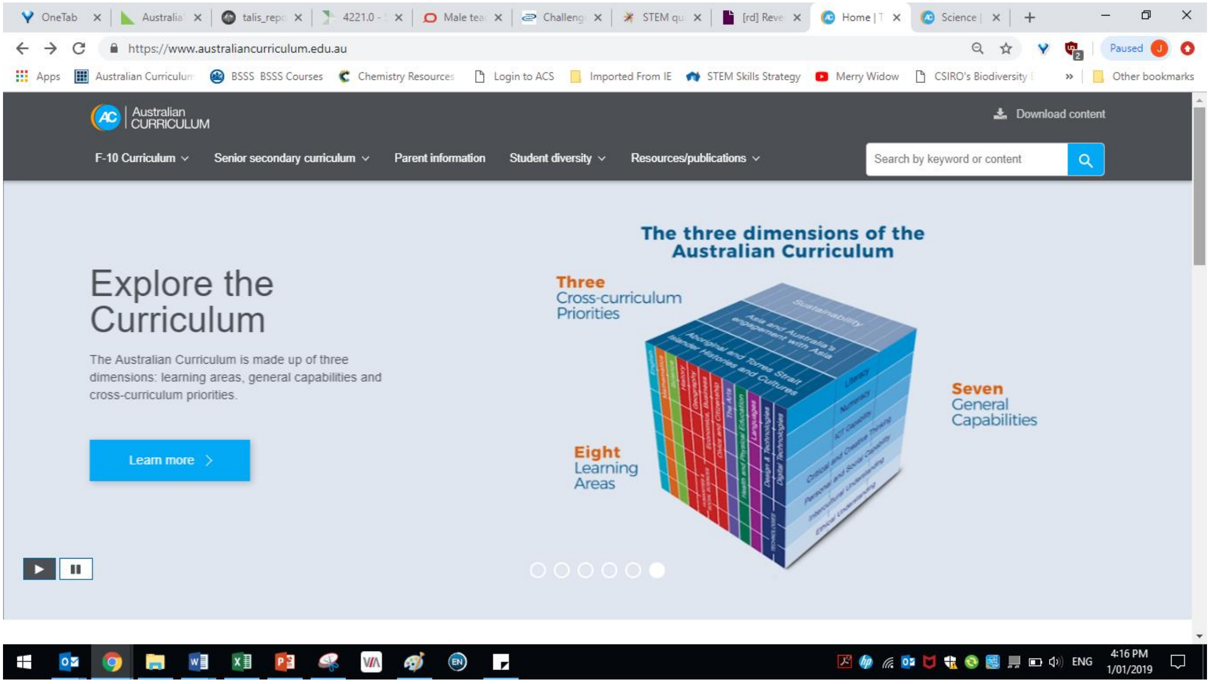

Figure 45 – Opening page of the Australian Curriculum website (ACARA, 2018b)

From this page, the grey navigation bar at the top allows you to access drop-down menus for the *F-10 Curriculum*, Figure 46.

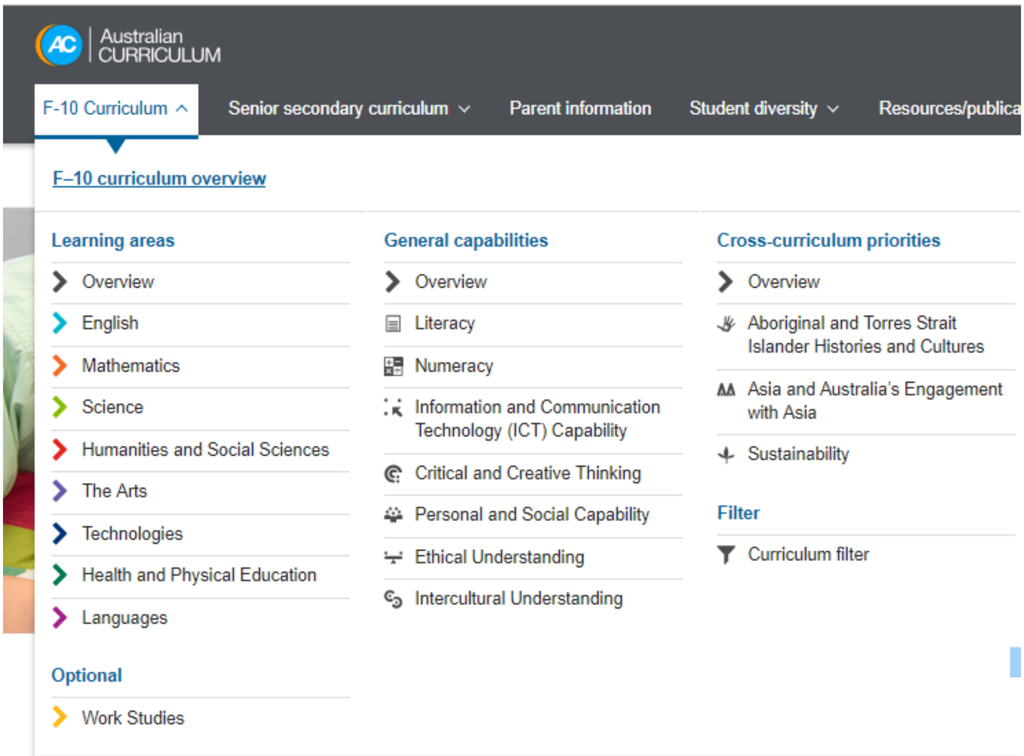

Figure 46 – F-10 curriculum overview (ACARA, 2018b)

You can follow the links to any of the nine compulsory Learning areas, the optional Work Studies, the seven General capabilities and the three Cross-curriculum priorities. You can also select the Curriculum filter which enables you to select from Subject, Year Level, General capabilities and Cross-curriculum priorities.

The senior secondary curriculum is accessed via the second grey tab, as shown in Figure 47.

Figure 47 – Senior secondary overview (ACARA, 2018b)

There are far fewer options from the Senior secondary curriculum drop down menu as the Australian Curriculum for Senior secondary years is not yet enforced nationwide.

Next in the grey navigation bar is a link to Parent information. This takes you to a brief overview of the curriculum with a link to a document explaining how the curriculum is organised as well as a range of handy links and frequently asked questions. Finally there is a link to a four-page document which provides an overview of each band of schooling (Foundation followed by two year levels at a time, Years 1-2 through to Years 9-10).

There are two other drop down menus, one for Student diversity, Figure 48, and finally Resources/publications, Figure 49.

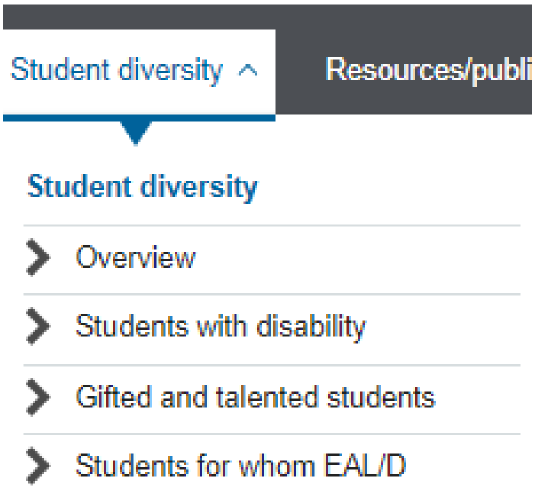

Figure 48 – Student diversity overview (ACARA, 2018b)

The Student diversity links take you to a page providing an overview of how the curriculum caters for particular groups of students, namely students with a disability, gifted and talented students and students for whom English is an additional language or dialect. Information is provided regarding these student groups, how learning can be personalised for these students, how the general capabilities can be utilised to support their learning, and links to references and/or further resources.

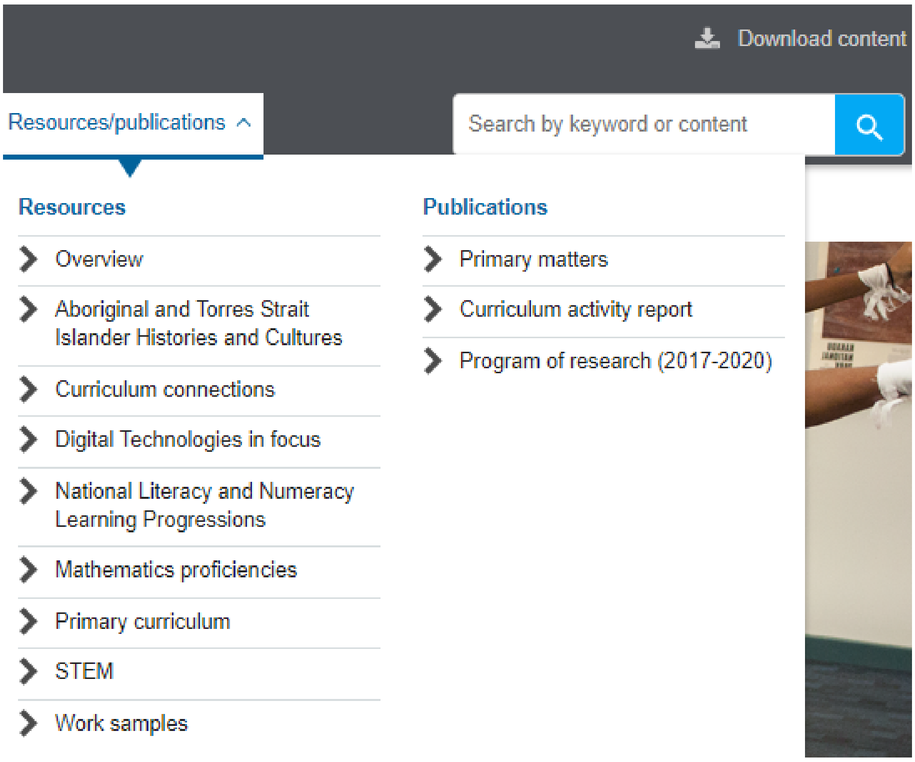

Figure 49 – Resources/publications overview (ACARA, 2018b)

The Resources/publications menu enables you to find additional resources on a range of specific aspects of the curriculum as well as to ACARA publications. The STEM link goes to a paper about a STEM Connections program run by ACARA and a number of schools. It focused upon how schools implemented STEM and so was omitted from this study.

Finally, as seen in the top right of Figure 49, you can search the entire website or click on the Download content button which takes you to Print/Download page from which you can select from the F-10 Curriculum, Senior secondary Curriculum, or Resources. The F-10 curriculum allows you to select from learning areas and subjects, year levels and curriculum elements. The senior secondary curriculum allows the same but with a selection from units rather than year levels. The Resources section allows you to download content descriptions, elaborations etc. in Excel format as well as sequence of content and sequence of achievement documents for each learning area and subject.

In addition to the top grey navigation bar, further down the opening page are icons with links to the same pages are provided as well as a Quick Find search function, Figure 50.

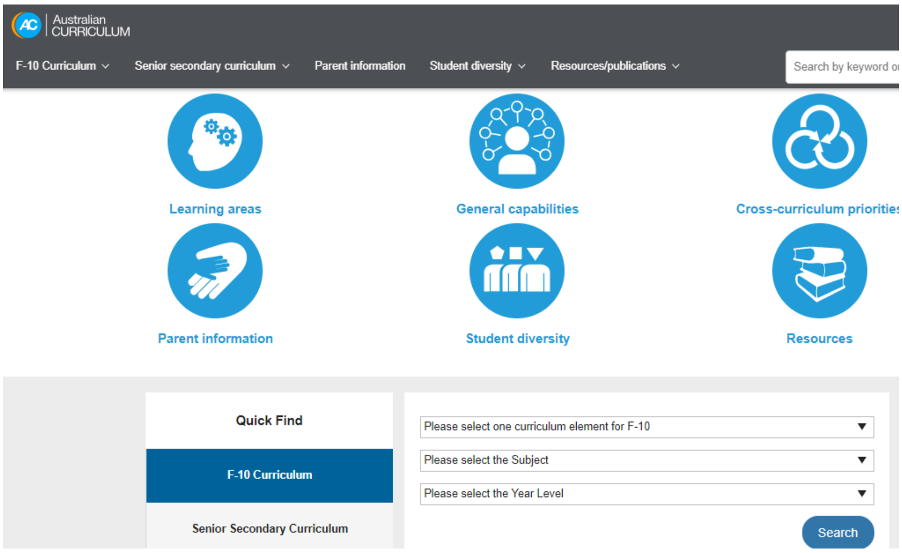

Figure 50 – Additional links on the opening page (ACARA, 2018b)

At the bottom of the opening page of the website are links to News items regarding the most recent releases and changes to content and format of the website, Figure 51.

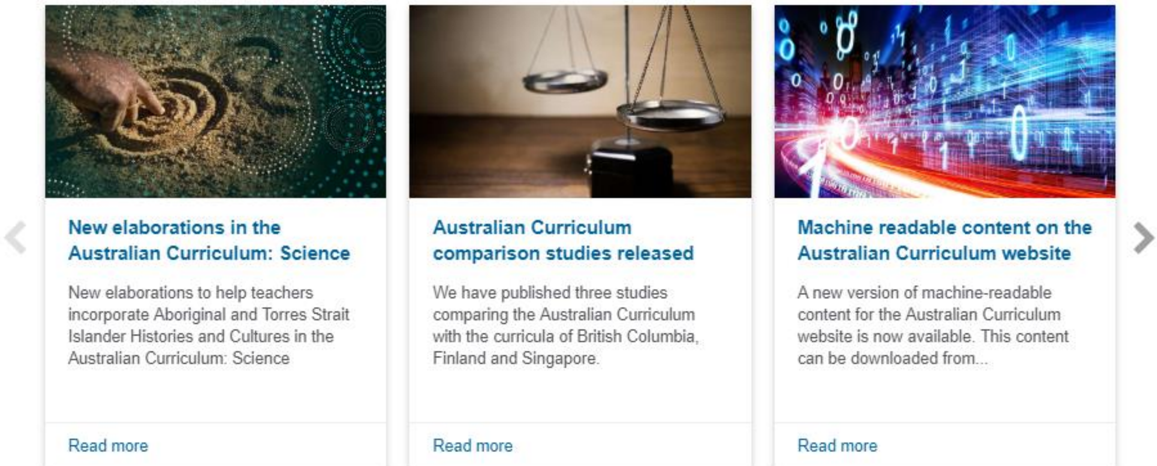

Figure 51 – Links to latest curriculum News items (ACARA, 2018b)

The Australian Curriculum is arranged around three dimensions, the Learning areas, General capabilities and Cross-curriculum priorities, as shown in Figure 52.

Figure 52 – Three dimensions of the Australian Curriculum (ACARA, 2018b)

The curriculum is structured so that the seven general capabilities and three cross-curriculum priorities are woven throughout each of the learning areas. The manner in which these three dimensions of the curriculum are presented on the website will now be briefly explained.

General capabilities

The general capabilities of the Australian Curriculum are: literacy, numeracy, information and communication technology (ICT) capability, critical and creative thinking, personal and social capability, ethical understanding and intercultural understanding. It is evident from this that the general capabilities are a focus of the Australian Curriculum as a means of ensuring that students develop, amongst other things, the skills they need to contribute meaningfully to their workplace and society. It is noted that

> Teachers are expected to teach and assess general capabilities to the extent that they are incorporated within learning area content. State and territory authorities will determine if and how student learning of the general capabilities is to be further assessed or reported (ACARA, 2013c)

Icons are used throughout the online sequence of content for subjects by way of indicating to teachers which content may be appropriate to use as a context within which to develop a capability, see Figure 53.

Figure 53 – The symbols used for tagging the General Capabilities (ACARA, 2013c)

To help teachers in the development of a common understanding of the general capabilities, and to assist them in planning their courses in a manner which enables their students to develop these capabilities, a range of support materials has been provided. First, each general capability has an introduction which outlines the underlying rationale for each capability and how it sits within the learning areas. Each general capability is made up of a number of elements and sub-elements and these underpin the learning continua provided for each capability. These continua are designed to map paths of development of the capabilities that teachers can help their students to progress along at their own pace. Finally each learning area has a document which provides a brief overview of the capabilities (this section is the same for each learning area) and a couple of paragraphs per capability which explain how that capability may be developed within that learning area specifically. The content within this document is included in the overall description for the general capability itself and was analysed from that document.

Cross-curriculum priorities

The other overarching component of the Australian Curriculum are the three cross-curriculum priorities: Aboriginal and Torres Strait Islander Histories and Cultures; Asia and Australia's Engagement with Asia; and Sustainability. These priorities were identified in the Melbourne Declaration as "key areas that need to be addressed for the benefit of individuals and Australia as a whole" (ACARA, 2011). Similarly to the general capabilities, the cross-curriculum priorities are designed to be addressed across the learning areas within appropriate contexts. There is another set of icons used for the cross-curriculum priorities throughout the website, as shown in Figure 54.

Figure 54 – The symbols used for tagging the Cross-curriculum Priorities (ACARA, 2011)

Each priority is described via an overview which indicates key concepts and associated organising ideas that are designed to help support the integration of the priorities within the learning areas. No learning continua are provided for the cross-curriculum priorities. A small amount of learning area specific advice is also provided to help teachers see how they may address the priorities within their learning area (ACARA, 2011).

Learning areas

There are eight compulsory learning areas within the Australian Curriculum: English, Mathematics, Science, Humanities and Social Sciences, The Arts, Health and Physical Education, Languages and Technologies. Most of these learning areas are comprised only of the subject of the same name with the exception of the Humanities and Social Sciences, made up of History, Geography, Economics and Business, Civics and Citizenship for Years 7-10, and the Technologies which is comprised of Design and Technologies and Digital Technologies.

Each learning area has a navigation page like that shown in Figure 55. From here you can filter by Year level, Strands, the General Capabilities and the Cross-curriculum priorities. The Additional Information tab allows you to select for the Elaborations and/or ScOT (Schools Online Thesaurus) terms to be shown.

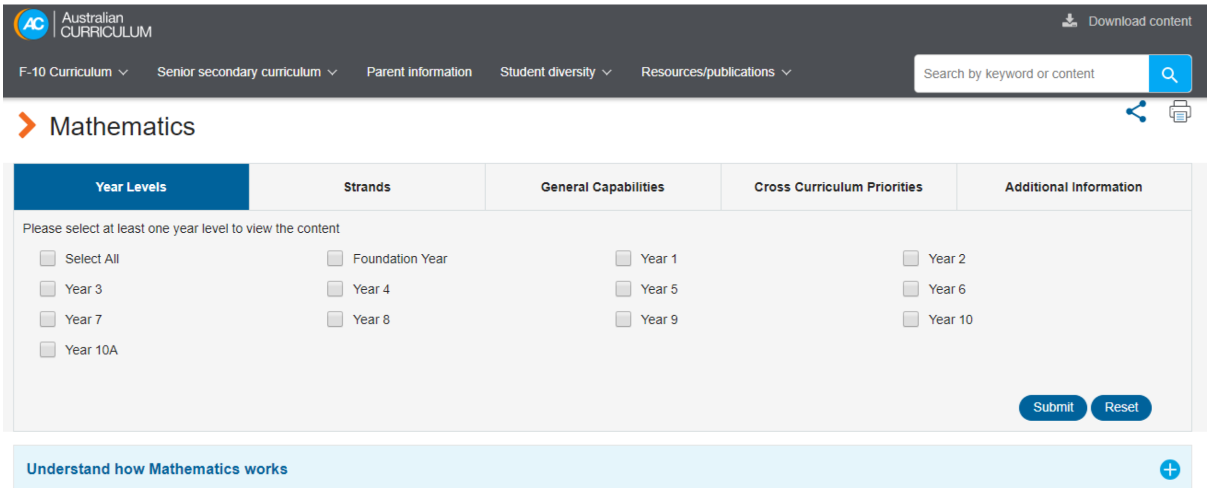

Figure 55 – Example of the navigation page for a learning area (ACARA, 2015i)

Expanding the Understand how Mathematics (or other learning area) works tab at the bottom gives you access to the items shown in Figure 56.

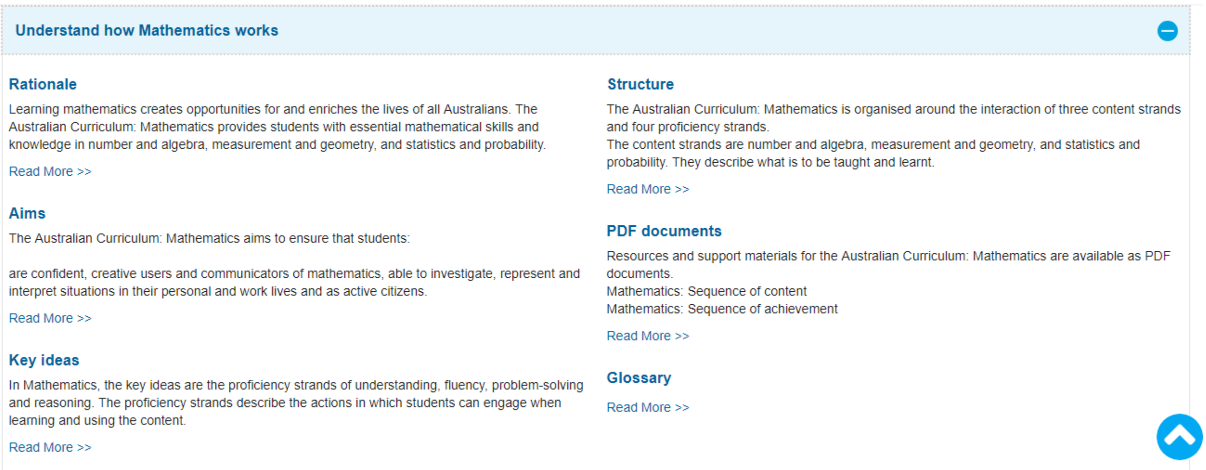

Figure 56 – Links to pages with information pertaining to specific aspects of the learning area (ACARA, 2015i)

The Rationale for each learning area is normally quite short, three to five paragraphs, and provides an overview of the subject area, the motivations behind it and what makes it a valuable area of study. The Aims for each learning area are articulated via a series of dot-points about what that learning area aims to ensure for the students undertaking it. The Key Ideas are generally small in number and serve as themes that permeate the learning area from Foundation through to Year 10. The Structure page provides information on how the curriculum of each learning area is structured as this varies to an extent from area to area. The Sequence of Content is provided as a PDF in table form which outlines each of the content descriptions within each strand of the curriculum for that learning area from Foundation to Year 10. Finally the Sequence of Achievement is another PDF tabular document with two paragraphs for each year level or band of years. In this way, the Sequence of

Achievement provides information on the depth to which students should understand and be able to demonstrate the knowledge and skills articulated in the content descriptions (ACARA, 2015s).

Selecting a year level from the menu in Figure 55 takes you to page with a Level Description (overview of how the content of that learning area is structured and the key content covered), Content Descriptions (short descriptions of key content which must be covered – identical to the content of the Sequence of content PDF), Elaborations (examples of how to address content descriptions, these are not available in the PDF version), Achievement Standards (identical to the Sequence of Achievement PDF) and Work Samples. The content descriptions are organised under strands relevant to the learning area. Each descriptor is tagged with icons pertaining to relevant general capabilities, Figure 53, and/or cross-curriculum priorities, Figure 54, to help teachers to see how these may be addressed within the learning area. Figure 57 shows an example of a content description with its associated elaborations from the Year 7 Mathematics curriculum.

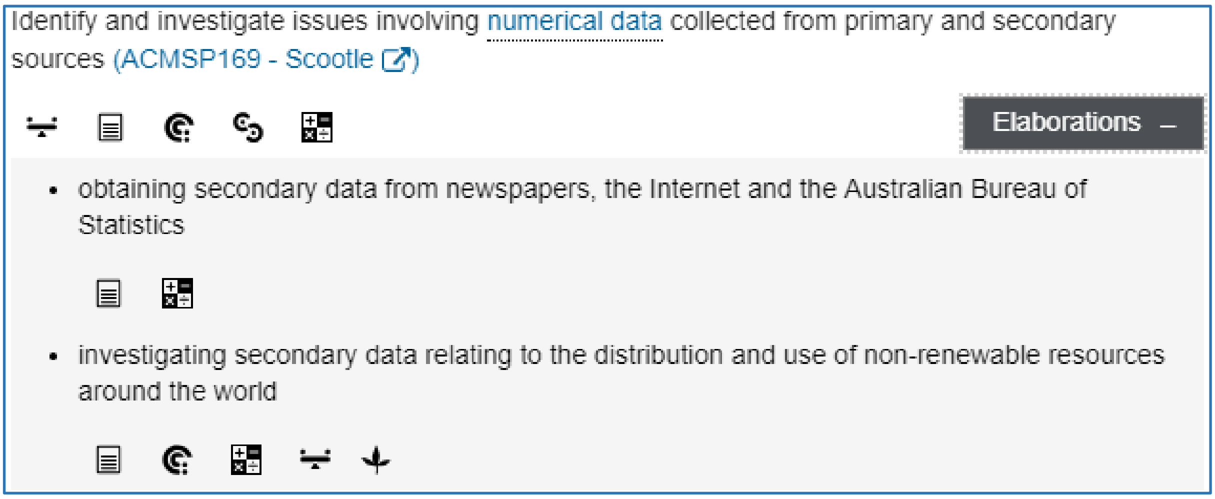

Figure 57 – Example of a content description and its associated elaborations (ACARA, 2015i)

Key phrases, in this case ‘numerical data’ are often written in blue, clicking on them provides a definition for the phrase. The blue writing in brackets at the end of the content description link out to Scootle, a website with digital resources that are aligned with the Australian Curriculum. The symbols immediately under the content description indicate relevant general capabilities (any relevant cross-curriculum priorities would be indicated here too). The grey box with ‘Elaborations’ inside was clicked to show examples of how this content description could be addressed (the dot points), each of these is also tagged with relevant general capabilities and/or cross-curriculum priorities.