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# What are the challenges for STEM education in the Australian context?

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*Doctor of Philosophy*

# Abstract

The introduction and implementation of STEM Education internationally and in Australia was centred around governments' concern for future economic growth and prosperity within a highly technology driven and global environment. Attention was also drawn to decreasing student enrolments in the physical sciences, higher level mathematics and engineering and technology-based courses and, the under-representation of females in tertiary engineering and, physical and computer sciences in schools and higher education. The literature review identified who led the introduction of STEM education and the multiple approaches available for its implementation.

This qualitative empirical study investigated the challenges facing STEM education in the Australian context. It was underpinned by a curriculum development framework and presented using a narrative inquiry approach. Data was collected and analysed from a document analysis, a Delphi study and semi-structured interviews.

A document analysis of thirty-two selected international and Australian documents related to the introduction and implementation of STEM education was undertaken to identify themes common to these documents. The selected documents were representative of government policies and programs, published research and reports from business, industry and professional associations and organisations. Five common themes were identified.

A Delphi study was conducted with eleven participants with a diverse range of experiences and positions in STEM education and the STEM disciplines from across Australia. The Delphi study sought to determine the purposes of and requirements for STEM education and whether a vision for STEM education in Australia in the Australian context could be constructed.

The semi-structured interviews were conducted with ten Delphi study participants and with an additional six selected participants. The interviews explored how the participants' conceptualisation of STEM Education shaped their approach to the implementation and future of STEM education in the Australian context.

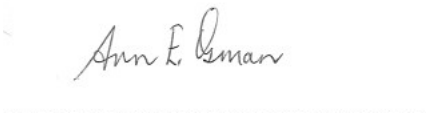
The study found three key challenges facing STEM education in the Australian context. The first challenge is that people have very different conceptualisations of STEM education which then hinders the design or implementation of STEM education programs. The second challenge is the establishment and sustainability of partnerships of people interested in STEM

education to develop programs to implement STEM education that are inclusive of all Australian students. The third challenge is the use of local contexts to better engage students in STEM education programs that are also relevant to global issues within the context of increasing accountability against set national and international standards

# Declaration

This is to certify that:

- The thesis comprises of only my original work towards the PhD except where indicated in the preface;
- due acknowledgement has been made in the text to all other materials used;
- the thesis is fewer than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.



Ann Elizabeth Osman

# Preface

This research was funded by the Australian Government Research and Training Program Scholarships fees offset.

The transcriptions of the sixteen semi-structured interviews conducted in this study and the formatting of the thesis were completed by *The Public Sentence* (http://www.thepublicsentence.com).

**Conference presentations related to the completion of the thesis**

Osman, A. E., Clarke, D. and van Driel, J. (2017, November): *Lifting the Veil from STEM Education: making sense of what's behind the veil.* A presentation at the STEM education Conference Deakin University. Waurn Ponds. Victoria. A. E. Osman was the sole presenter with contributions to the content of the presentation from Professor D. Clarke and Professor J. van Driel totalling twenty percent. The material included in this presentation related to the usefulness of a Delphi study to gather opinions and ideas about an issue and the steps involved in undertaking a Delphi study as discussed in chapter 3, sections 3.2.3 and 3.2.4

Osman, A. E., Clarke, D. and van Driel, J. (2017, November). *STEM now: Why bother?* A presentation at the annual conference of the Australian Association for Research in Education (AARE) Conference: *Education: What's politics got to do with it?* Canberra Australia. A. E. Osman was the sole presenter with contributions to the content of the presentation from Professor D. Clarke and Professor J. van Driel totalling twenty percent. The material in this presentation was relevant to the application of the document analysis to better understand published policies and strategies to implement STEM education as discussed in chapter 4.

Osman, A. E., Clarke, D. and van Driel, J. (2018, March): *STEM education: Origins and Implications from an Australian Perspective.* A poster session presented at the 2018 NARST Annual International Conference: *Re-centering on Scientific Literacy in An Era of Science Mistrust and Misunderstanding* in Atlanta, GA, USA. The sole presenter was A. E. Osman with contributions to the content of the poster from Professor D. Clarke and Professor J. van Driel totalling twenty percent. The poster displayed material relevant to the curriculum development framework and from the document analysis as discussed in chapters 2 and 4 respectively.

Osman, A. E., Clarke, D. and van Driel, J. (2018, November): *The Application of a Delphi Study to Navigate Safe Passage Through STEM Education Research.* A presentation at the

annual Contemporary Approaches to Research (CAR) Symposium, Melbourne, Australia. The sole presenter was A. E. Osman with contributions to the presentation from Clarke and van Driel totalling twenty percent. The material in the presentation illustrated how a literature review could be used to construct a Delphi study as discussed in chapters 2 and 3 respectively.

Osman, A. E, Clarke, D. and van Driel, J. (2018, December). *Venturing into The Unknown.* A presentation at the annual Australian Association for Research in Education (AARE) Conference: *Education Research Matters: Impact and Engagement*, Sydney Australia. A. E. Osman was the sole presenter with contributions to the content of the presentation from Professor D. Clarke and Professor J. van Driel totalling twenty percent. The material included in the presentation highlighted the benefits of conducting a Delphi study to better understand how a group of selected participants understood an issue as discussed in chapters 3 and 5 respectively.

Osman, A. E., Clarke, D. and van Driel, J. (2018, December). *Where to Now for STEM Education?* A presentation at the annual Australian Association for Research in Education (AARE) Conference: *Education Research Matters: Impact and Engagement*. Sydney Australia. A. E. Osman was the sole presenter with contributions to the content of the presentation from Professor D. Clarke and Professor J. van Driel totalling twenty percent. The material included in the presentation was relevant to the findings from the document analysis and Delphi study is discussed in chapters 4 and 5 respectively.

Osman, A. E., Clarke, D. and van Driel, J. (2019, July). *STEM Education: How New?* A presentation at the annual Australian Science Education Research Association (ASERA) *Celebration 50 years of Science Education Research.* Conference. Queenstown. New Zealand. A. E. Osman was the sole presenter with contributions to the content of the presentation from Professor D. Clarke and Professor J. van Driel totalling twenty percent. The material included in the presentation was relevant to the visions developed from the Delphi study as discussed in chapter 5.

Osman, A. E., Clarke, D. and van Driel, J. (2019, December). *STEM Education in the Australian Context: How New?* A presentation at the annual Australian Association for Research in Education (AARE) Conference: *Education for A Socially-Just World.* Kelvin Grove. Australia. A. E. Osman was the sole presenter with contributions to the content of the presentation from Professor D. Clarke and Professor J. van Driel totalling twenty percent.

The material included in the presentation was relevant to the visions developed from the Delphi study as discussed in chapter 5.

# Acknowledgements

The completion of this study owes much to the guidance, patience, wisdom and time so generously provided to me by my academic supervisors from The Melbourne Graduate School of Education, Professor Jan van Driel, Professor David Clarke, Professor John Polesel and Dr. Victoria Millar. I thank them for their encouragement and support without which the thesis would not have happened.

I thank all the participants in this study for their generosity and honesty when sharing their ideas and opinions and the time they gave to completing all tasks asked of them. The participants cared about the education of all young Australians and I trust that this is evident in the way in which their opinions have been presented in this thesis.

I thank my friends and colleagues Dianne and Chris White, Marion White, Jo Fern, Karen Ivanka, Dr. Merryn Dawborn-Gundlach, Emma Stevenson, Dr. Rhonda DiBiase and Carmel Mesiti for their words of encouragement, support, advice and humour from the beginning of my return to post graduate study to the completion of this thesis.

Lastly and most importantly, this thesis is dedicated to my parents, Lucy and Ray Osman, who always believed in the value of education and to all the students that have ever entered my classrooms, trusting that they would learn something that mattered to them and that this mattered to me.

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# Chapter 1: Introduction

## 1.1 Why STEM education?

On 20 October 2019, the municipality of Whitehorse in the Australian state of Victoria announced the annual *Spring Festival: Celebrating Whitehorse* (News Corp Australia, 2019):

> STEM Learning- all things science, tech, engineering and maths -Your Passport to the Future. (2019: p.1)

The festival program provided a wide variety of STEM-themed activities including a planetarium, science shows with simple experiments and high-tech type demonstrations, building simple and complex structures and robots with Lego blocks, prizes for the best dressed STEM resident, for example, as a robot or mad scientist or inventor and encounters with animals and insects. The festival encouraged all residents regardless of age to participate and to learn more about STEM.

As a resident of the Whitehorse municipality, I was delighted to see a focus on STEM learning and the future for young people and the involvement of the community. However, as an educator I was concerned that a one-off high-profile event focussed on STEM learning whilst well intended, would not have a lasting impact unless follow up and sustainable programs were provided.

I believe that there is a real danger of portraying STEM education as the panacea for all that is amiss, for example, loss of global economic competitiveness, insufficient innovation and creativity in generating new jobs and prosperity, too few women employed in STEM areas and falling performance by Australian school students on international tests.

STEM education could be and should be more than this. I believe it represents an opportunity to re-imagine education rather than the more negative view, which is to reform education.

This study provided an opportunity:

- for selected participants to reflect on past initiatives and achievements in education to better understand the possibilities for and benefits of STEM education for all Australian students;
- to investigate if it is possible to develop a shared vision for STEM education and its implementation in Australia;

- to explore international research in STEM education and its relevance to Australia and to contribute to the global research in STEM education;
- to develop a research design that could be applicable to other investigations into STEM education;
- to document and acknowledge and learn from past initiatives in science education through understanding the context, direction and the political, economic and social influence that set the agenda for these initiatives.

The study asked if these initiatives provided the groundwork for STEM education and what lessons past attempts at reforming science education can provide to facilitate the effective implementation of STEM education? Or is STEM education simply the latest incarnation of previous programs to reform school science education such as the use of open-ended inquiries linked to local issues? Initiatives such as Science for All, Science, Science Technology and Society, Scientific literacy and Science as a Human Endeavour have gained and waned in prominence over time. These initiatives were grounded in research and expressed a genuine desire to improve the quality of teaching and learning in and engagement with science. The current initiative attracting attention is the implementation of STEM education. What concerns me is that rather than providing the base on which STEM education builds, gains made by past initiatives may become lost unless the narratives of those who were active in these earlier initiatives are documented.

### 1.2 A Roadmap for finding your way through the thesis

A narrative inquiry approach was be used to present this study, beginning with a review of literature, followed by a discussion of the methodology employed, presentation of the findings and a discussion of the implications of this study for STEM education in Australia and possibilities for further research.

The literature review introduced the curriculum development framework that underpinned this study. The framework reflected the work of selected education researchers with expertise in curriculum The introduction and implementation of STEM education internationally and in Australia was the investigated.

The literature review provided a historical perspective to the introduction and implementation of STEM education internationally and in Australia through the identification of relevant and key policy documents and research reports.` These included, for example, governments setting the directions for the introduction or implementation of STEM education

and research studies of STEM education programs. The documents selected for analysis were related to the introduction and implementation of STEM education and were drawn from the "published authority", that is the international and Australian documents that were authored or commissioned by governments, statutory authorities, groups representative of business or industry and professional associations. The analysis of the selected documents included the identification of any recurring themes. These themes were used to inform the construction of the Delphi study and the semi-structured interviews conducted with the participants selected to undertake the research.

The analysis of the data from the Delphi study led to the construction of visions for STEM education in the Australian context. Participants in the study were then asked to choose their preferred vision and to explain their choice.

### 1.3 The development and implementation of education in the Australian context

Australia is a federation of the colonies that were established after the arrival of the First Fleet in 1788 in what was known as New South Wales. In the late nineteenth century the six existing separate self-governing colonies of Queensland, New South Wales, Victoria, Tasmania, South Australia and Western Australia conducted a series of referenda that led to establishing a system of federalism in Australia to form the Commonwealth of Australia from 1 January 1901. In agreeing to form the Commonwealth of Australia, the colonies ceded some of their powers to the Commonwealth (for example defence and customs) but retained others, including responsibility for education and health. The two territories, Australian Capital Territory (ACT) and the Northern Territory (NT), were included in the Commonwealth of Australia in 1911.

Funding for education in Australia is provided by both the Commonwealth government and the individual governments of the seven states and two territories that make up the Commonwealth of Australia. The Australian Curriculum Assessment and Reporting Authority (ACARA) was established in December 2008 to oversee the development of the Australian Curriculum for primary and secondary school education, the inclusion of new initiatives such as STEM education and the implementation of national assessment programs.

The individual states and territories, known as jurisdictions, remain responsible for the implementation of the published Australian Curriculum. Each jurisdiction has adapted the Australian Curriculum to its own situation. Consequently, the implementation of Australian Curriculum looks different across Australia. For example, in New South Wales the Australian

Curriculum has been integrated into the existing Education Standards Authority curriculum structure and in Victoria as the Victorian Curriculum F-10.

Each jurisdiction is also responsible for the registration of its schools and teachers. Within each jurisdiction, there are government or state schools, Catholic schools based on the Archdioceses and Dioceses, independent schools including faith based, community or Steiner schools and home schooling. Government schools are expected to implement the Australian Curriculum as approved and published for their jurisdiction. The situation for the Catholic school sector is like that for government schools, with independent schools able to choose to implement the Australian Curriculum or other curricula provided government requirements for registration and funding are met.

### 1.4 The development of curriculum in the Australian context.

In the late 1980s and early 1990s in a climate of relative political stability and harmony, attempts were made by the Ministers of Education from the Commonwealth, state and territory governments to introduce a national curriculum with specified content and achievement standards. This led to the first of three successive declarations of education designed to set a vision to provide direction for education in Australia that would ultimately lead to a national curriculum.

The first declaration in 1989, known as *The Hobart Declaration of Education,* sought to develop a relevant and excellent education for all young Australians that would enable them to achieve high standards of learning and personal self-worth and prepare them for further education that would enable them to contribute to the economic prosperity of their community. The declaration provided ten agreed national goals for schooling in Australia that focussed on curriculum and assessment and establishing a framework for collaboration between schools, systems and governments to develop appropriate objectives and strategies to implement the goals.

This historic declaration saw the inception of the Curriculum Corporation of Australia, now known as Education Services Australia, which was responsible for developing and providing curriculum and assessment materials aligned to the ten goals. The declaration also adopted a future focussed approach to education and established a process to review the goals in a timely manner to enhance the capacity of all Australians schools to meet the challenges of the twenty-first century.

The political climate had changed, with the Commonwealth Government focussed on driving economic and workplace reform, when the second declaration in 1998 known as *The Adelaide Declaration on National Goals for Schooling in the Twenty-First Century* was released. The number of goals included was reduced from ten to three. The emphasis of this declaration remained focussed on continuing education and training of all young Australians and ensuring their contribution to a prosperous community. It also highlighted the importance of education to economic development in a local and global context. This anchored economic prosperity as a driver of education. The language of the goals was aspirational, demanding, for example, that schools be socially just centres for learning where the talents and capacities of all students are fully developed.

When the third declaration, *The Melbourne Declaration of Education Goals for Young Australian,* was published in 2008, the Commonwealth Government had an increased focus on social justice within a growing economy. The declaration continued to focus on the importance of ongoing education to enable young Australians to contribute to the prosperity of their community in the twenty-first century. In this declaration, emphasis was placed on the rise of globalisation, the need for innovation, rapid changes in the type, access to and use of technology, the rise and influence of Asian nations, improved student literacy and numeracy, developing skills for the changing employment opportunities and equity and access to education for indigenous Australians. The declaration placed young Australians at the centre of schooling with two succinct goals. These were "Australian schooling promotes equity and excellence" and "All young Australians become successful learners, confident and creative individuals, active and informed citizens" (2008: pp.6-9).

This declaration also reinforced that responsibility for achieving these goals rested with a collective of governments, school sectors and individual schools as well as parents and carers, young Australians, families and other education and training providers, business and the broader community. The Melbourne Declaration led to the development of the national curriculum that became known as the Australian Curriculum. It is into this curriculum that STEM education programs have been included.

From European settlement in Australia, education was provided in government schools, church schools and community schools. The curriculum offered focussed on developing the students' reading, writing and arithmetic skills and from the 1930s included general subjects with a focus on work and life skills subjects. Some vocational education had been included by some states from the 1920s to provide more secondary and technical education. Access to

secondary education and tertiary education was initially limited and largely followed the curriculum of the United Kingdom with enrolments expanding significantly from the late 1950s.

With federation in 1901 the Commonwealth also became involved in education and developed and implemented significant reforms in education in conjunction with the states and territories. A snapshot of these relevant to STEM education is listed below:

- 1960s: the provision of *Commonwealth Science Laboratories* and the use of USA education programs such as *PSSC Physics* (from USA) in schools in response to the interest in science generated by the race to conquer space.
- mid 1970s: the *Karmel Report* into schooling in Australia where the Commonwealth Government became an active participant in funding programs for disadvantaged schools.
- 1987-1993: National Curriculum Statements and Profiles which was an attempt to develop and implement a national curriculum for Australia.
- 1985: introduction of Vocational Education and Training (VET) in schools
- 1995- : ongoing participation in national and international testing/evaluation programs for example, NAPLAN, TIMSS and PISA.
- 2001: *The status and quality of teaching and learning science in Australian schools* prepared by Dennis Goodrum, Léonie Rennie and Mark Hackling.
- 2008: the establishment of ACARA (Australian Curriculum Assessment and Reporting Authority).
- 2009: beginning the development of the Australian Curriculum.

The provision of science laboratories in the 1960s and 1970s supported a shift in focus of the general science subject of the 1930s-1950s to include modern developments in science. This was driven by politicians in response to the public to demanding more science education in schools. This was evident in projects that encouraged specialised education in the sciences and general science studies at secondary and primary school level in countries such as the UK, New Zealand, USA and Malaysia (Fensham 1985). For example, the USA (1960) Physical Science Study Committee (PSSC) modernised traditional high school physics with the publication of textbooks, course materials and educational movies through the 1970s and 1980s that were quickly adopted for use in Australian schools.

For the purposes of this thesis, curriculum includes the intended or published curriculum and the enacted curriculum as interpreted and implemented in the education settings. The parameters and opportunities for STEM education have been set in policy documents, for example, *VicSTEM* (2016), from which the intended curriculum is constructed. How this curriculum is enacted in the different education settings is dependent on how the policy documents are understood and translated into a curriculum by those responsible for its implementation.

For example, the Australian Curriculum (AC), includes achievement standards and examples of learning opportunities, possible pedagogical approaches and assessment tasks that will demonstrate if students have reached the required standard. This published curriculum document is much more than just knowledge and skills to be delivered.

The Australian Curriculum consists of three interconnected components. These are the learning areas (LAs), the general capabilities (Gcs) and the cross-curriculum priorities (CCPs). There are eight learning areas, seven capabilities and the three cross-curriculum priorities. It is into this structure that STEM education was to be included.

For the purposes of this thesis, STEM education includes:

- formal education in the domains of Science, Technology, Engineering and Mathematics as provided in pre-schools, primary and secondary schools, higher education and training;
- professional learning education or development as required to maintain registration or certification in a profession;
- education programs provided at museums, art galleries, public lectures
- on the job education and training;
- self-education to improve, refresh, extend knowledge and skills, or personal interest. (This may be linked to a profession or occupation or to hobbies or recreational interests.);
- informal education as provided through the media, internet searches or social settings.

### 1.5 What do I want to achieve from this study?

The review of relevant policy documents, programs and research will provide a historical perspective of the emergence of STEM education in Australia and other countries. I

am seeking to determine what may have influenced or driven reforms to education within the social, economic and political context at a specific time with a focus on Australia. This would include an investigations of how initiatives or programs to address these reforms were developed and included into the curriculum and the factors that impacted on the success or otherwise of the reforms.

I am also seeking to identify if a coherent vision and strategy for STEM education in the Australian context exists and any challenges to its effective and successful implementation. The analysis of the data collected will likely provide some examples as to how to successfully implement STEM education programs and offer advice as to how to avoid possible mis-steps and to identify and heed warnings that all is not going well. This may also suggest further research that may be needed to address these challenges.

The next chapter details the development of the curriculum development framework to underpin this study and reviews literature that addresses the introduction and implementation of STEM education internationally and in Australia.

# Chapter 2: Literature review

This chapter reviews and discusses the introduction and implementation of STEM education internationally and in Australia. The work of six international and three Australian education researchers with expertise in curriculum was studied and led to the application of a curriculum development framework to underpin a study of challenges for STEM education in the Australian context. The research questions to be addressed in this study are presented.

## 2.1 Introduction

Since the term STEM entered the lexicon globally there has been a steady increase in the number of publications seeking to define it and to encourage people to embrace it. It has been expanded to include the development and implementation of programs in STEM and the introduction of the term STEM education. As Australia has drawn on education reforms from the United States of America (USA) and the United Kingdom (UK) in the past, the literature review initially focussed on these two countries and then extended to an overview of STEM education in other countries.

The use of a curriculum development framework provides a lens to examine how the political, economic and social context that led to the introduction of STEM education influenced and shaped the development of curriculum and programs designed to deliver specified outcomes. This also supports an investigation into how key or influential stakeholders who have initiated or designed or evaluated past reforms in education in Australia conceptualise STEM education and its implementation.

An internet search of publications related to the introduction of the terms STEM and STEM education identified the authors or owners of these publications. It was found that this rested with governments at the national, state and local levels; bureaucracies and public servants; business and industry; the disciplines of Science, Technology, Engineering, Mathematics and Education; eminent researchers; professional associations; and international bodies such as the United Nations Educational, Scientific and Cultural Organisation (UNESCO). This group formed the collective referred to in this study as the published authority.

Examples of the published authority in this study were government departments of education from the USA and UK and the Office of the Chief Scientist (Australia) and academic researchers including Carla Johnson from the USA and Peter Fensham from

Australia. Also included were professional associations, for example, the Royal Academy of Engineers, (RAE, UK ), the National Science Foundation (NSF, USA) and the Australian Council Of Learning Academies (ACOLA). The Australian Advanced Manufacturing Council (AAMC) provided a business and industry perspective on STEM education.

## 2.2 The curriculum development framework

### 2.2.1 Introduction

Governments, business and industry have argued that there is a need for workers with STEM knowledge and skills to drive innovation and generate increased economic and social prosperity. This has focussed attention on the development and implementation of STEM education programs in schools and higher education and training. This has led to the renewed interest in the type of curriculum and the pedagogical and assessment practices best suited to deliver STEM education programs.

The development of the curriculum development framework for this study drew on the work of selected international and Australian education researchers with expertise in curriculum. The following sources and criteria were used to select the education researchers:

- the political or economic or social contexts in which their work was undertaken and their status, for example, additional funding to support science and technological developments such as space exploration or to increase student achievement on international tests;
- membership of prestigious committees, for example, chair of national or international committees related to education;
- authorship of government policies or reviews or reports, for example, a national curriculum document or programs to address inequities in the participation of specific groups of students;
- lists of publications, for example, in peer review journals or editor of books or journals related to curriculum design or research;
- the relevance and application of their work to STEM education in the Australian context, for example, development of strategies to review or develop curriculum within a local or national context.

### 2.2.2 The international selected education researchers with expertise in curriculum

Using the above selection criteria, the six international education researchers selected were Thomas Huxley, John Dewey, Ralph Tyler, Joseph Schwab, Michael Young and Rodger Bybee. These education researchers offered expertise in the design of curriculum and experiences in the development and implementation of policies and programs related to curriculum.

Thomas Huxley (1825-1895) was largely self-educated in biology although he formally trained as a doctor. Huxley visited Australia and New Guinea in 1846 serving as an assistant surgeon on HMS Rattlesnake where he collected and studied marine invertebrates. Publications of his findings from this research were well received by the Royal Society and served to introduce him to the academic community. As a biologist, Huxley vigorously supported Darwin's theory of evolution. Huxley (1854), when working as the Professor of Natural History at the School of Mines (UK), took the opportunity to promote and recognise the use of laboratory work in biology to develop students' skills, knowledge and understanding.

Huxley supported a liberal education for school students and encouraged further education for people beyond school because "the masses should be educated because they are men and women with unlimited capacities of being, doing and suffering, and that it is as true now, as ever it was, that people perish for lack of knowledge" (1868: p.76).

Huxley also championed the education of all people, not just those from the elite or privileged backgrounds. Huxley emphasised the acquisition of knowledge and the application of methods of investigation research as being a core component of a liberal education. It could be argued that Huxley's focus on the development of skills in the education provided to all people was like the development of STEM skills as being crucial for all people in the twenty-first century.

John Dewey (1859-1952) linked learning, the curriculum and the child with a focus on the provision of learning experiences commensurate with the child's interests (1902). It could be argued that Dewey equated learning to the acquisition of knowledge and skills. Dewey was a philosopher and seen as a progressive educator who presented a curriculum for a learning centred school or classroom that focussed on the needs of the learners by providing experiences as learning opportunities that will assist the child to become a mature adult. Dewey identified the educative process as the interaction between "an immature undeveloped

being" and "certain social aims, meanings, values incarnate in the matured experience of the adult" (1902: p.4).

Dewey strongly argued that the child brings experiences and understandings to the classroom that although transient, should be recognised as the starting point for school or *formal* education. Dewey also believed that education should develop the child's capacities in a way that best suits them and will allow them to function within their community. Dewey argued that if the curriculum is developed specifically for the teacher, it would then provide direction as to how and what the child needs to learn to become the mature adult. The teacher would be responsible for choosing the learning experiences and stimuli that supported each child to reach the maturity expected by the community. Dewey continued that if the teacher provides the same learning experiences to all children at the same time, so treating all learners as a single entity, this would undervalue the interests, experiences and expectations that the individual brought to the classroom. It could be argued that this was similar to the current initiatives that support the differentiation of the curriculum and assessment tasks to ensure the emphasis is placed on addressing the student's needs and interests as the learner.

Dewey believed that being able to synthesise and analyse information and apply scientific inquiry to solving problems supported student learning. It could be argued that this equates to the skills of problem solving and creative and critical thinking that are often included in the workplace skills that employers argue are essential to grow economic prosperity in the twenty-first century.

Dewey's approach of developing a curriculum that emphasises providing learning experiences that build from the individual's interests and needs is contrary to one that emphasises activities or learning experiences that build a defined set of STEM knowledge and skills. It could be argued that if STEM education programs provided activities that are age appropriate and relevant to all students then they would be encouraged to pursue studies in the STEM disciplines.

Ralph Tyler (1902-1994) organised the curriculum using educational objectives expressed in terms of changing behaviours to produce specific outcomes and included methods for evaluating if these outcomes had been achieved. Tyler was initially an educator in the natural sciences and is often considered to be the *father* of the inclusion of behavioural objectives in curricula. Tyler presented learning as taking place through "active behavior of the student. It is what he does that he learns, not what the teacher does" (1949: p63).

Tyler's set of principles for curriculum development are still visible in some current curricula, particularly those structured around achievement standards like the Australian Curriculum.

Tyler (1949: p.1) argued that curriculum should be developed by considering the educational purposes, the provision of educational experiences that deliver these purposes, the effective organisation of the educational experience and evaluation as to whether these purposes have been achieved. This led Tyler (1949) to develop a curriculum that consisted of three components and was centred on behavioural objectives for the learner. First was a set of elements (1949: p.89) which included concepts, values, skill, abilities and habits. Second were the organising principles (1949: p.97) which included the breadth of application of the elements and the description and analysis required to build a holistic curriculum. Third were the structural elements (1949: p.98), such as the inclusion of specific subjects or broad fields or a core curriculum or a completely undifferentiated structure of the curriculum. It could be argued that the inclusion of both specific subjects in the STEM disciplines and a more general science subject that drew on these disciplines would produce both the specialists and technicians required to grow economic and social prosperity in the twenty-first century. The components of the curriculum could be likened to the *organisers* of the current Australian Curriculum presented as rationale, aims, key ideas, structure of strands, content and achievement standards and, scope and sequences.

Tyler believed that evaluation was the process for determining if the planned changes in behaviour as specified in the outcomes had occurred and to what extent. Tyler also suggested that such evaluation should occur more than once in the educational program, most usefully at an early stage and then later and be based on evidence gathered from multiple sources as applicable (1949: pp.107-108). He believed that the role of the teacher was pivotal in the ongoing evaluation of the educational objectives.

Tyler suggested (1949: pp.124-125) evaluation provides a way in which the educational objectives can be clarified for teachers, ensuring they select learning activities that suit their students and are able to better inform parents of their child's progress and achievement.

Tyler's emphasis on the evaluation of the learning outcomes for all students may be seen in the current processes of continuous assessment as evident in many current government education policies. It suggests that the evaluation of the student learning against

specific outcomes would be a useful tool in determining the effectiveness of STEM education programs.

Joseph Schwab (1905-1988) authored four seminal papers from 1969 to 1986, that are referred to as Practicals 1, 2, 3 and 4. These practicals discussed the language and construction of the curriculum and who should be responsible for the development, review and revision of curriculum. Schwab (1958: pp.374-379) believed strongly that *teaching was an art.* Schwab's background was in English literature and biology and he worked in the areas of educational theory and practice and the philosophy of science. Schwab was also a key figure in the Biological Sciences Curriculum of Studies (BSCS) project with a passion for teaching and learning in science as an ongoing process of inquiry - not the memorization of facts - and pursued research that sought to reconceptualise the teaching of science at all levels. Schwab also defended the re-establishment of a liberal education. Schwab introduced the terms *practical*, *quasi-practical* and *eclectic* into discussions about curriculum to demonstrate the application of his curriculum theory.

In Practical 1: *A Language for Curriculum,* Schwab (1969: pp.1-23) argued that there was a *crisis* in the field of curriculum theory as the dominant force in driving curriculum development had been in attempts to make the curriculum *teacher proof*. Schwab believed that *renaissance was possible* only if a shift in focus away from theory of curriculum to the practical of the curriculum was made. This practical described the approach to curriculum as a process where the learning experiences are presented to the students as problems to solve. Data is collected and then used by the students to refine the problem and to search for solutions. This approach can be recognised in the design process referenced and addressed in the Technology and Engineering disciplines of STEM.

In Practical 2: *Arts of Eclectic* 2 (1971), Schwab introduced another dimension to the curriculum that he labelled as *quasi-practical* (1971: pp.439-542). This was presented as a natural extension of the first practical and focussed on communicating the ways in which different variations of the original problem were accommodated and if the solution is in the best interests of those affected by it. This was described as considering the consequences of the solution that may extend beyond the context in which the decision was made. It could be argued that the implementation of practical 2 required flexible, creative, innovative and ethical approaches to solving problems that would complement the application of using the STEM knowledge and skills to solve twenty-first problems. This practical also illustrated Schwab's position that there is no one theory that is uniquely applicable to a situation. The

features of each problem can be guided by a theory that might bring incongruences that must then be adjusted using other theories or characteristics of another theory. How this application has been adjusted and modified demonstrates practical 2 as sourcing knowledge, understanding and information from multiple sources to complete the task. Schwab's approach to curriculum development supports a multi-discipline or integrated approach to the delivery of STEM education.

In Practical 3: *Translation into Curriculum,* Schwab (1973: pp.501-552) argued that the curriculum represented a practical process where problems are posed and deliberated on to make defensible solutions that apply to a specific setting and cannot be directly transferred to another setting. Schwab (1973: p.501) suggested that new educational materials and purposes can be generated when the curriculum is seen as a practical process. Schwab (1973: pp.505-504) further argued that to produce or review a curriculum required a partnership that included academics, schools, teachers and community. Schwab suggested that all members of the partnership should have equal status when making decisions about a curriculum that is best suited to progressing student learning.

In Practical 4: *Something for Professors to do,* Schwab (1983: pp.239-265) argued that the development of new resources would need to adopt a deliberative action stance to ensure the new curriculum was implemented as intended. This approach is reflected in the partnerships required for STEM education as discussed by Breiner, Harkness, Sheats, Johnson and Koehler (2012).

It can be argued that when considered as four contributing parts to the whole, Schwab's four practicals provide both a practical and a theoretical road map for curriculum development, implementation and evaluation that could be applicable to STEM education. However, whether all teachers have the necessary knowledge, skills, experiences and time to develop curriculum at their school that would deliver the intended outcomes required at a systems level warrants further investigation.

Michael Young (1934- ) brings an educational sociologist's view to the construction of curriculum and what constitutes knowledge and how this is voiced within the curriculum. Young also investigated the potential impact that policies that preference generic and skills-based curricula may have on knowledge acquisition.

Young (1971: p.20) suggested that public debates in the United Kingdom from 1950-1970 had focussed on "equal opportunity", "wastage of talent", "organisation and selection of

pupils" and the "curriculum". Young believed that the curriculum had become focussed on the implementation of government policies related to increasing the participation in science and technology subjects, increasing the age for compulsory school attendance and the provision of more comprehensive education settings. This approach provided for the continuing external control of what was included in the curriculum rather than accommodating more teacher autonomy as discussed by Schwab (1973). Young (1971) suggested that teachers could focus on developing students' knowledge in local contexts but cautioned that this would require a lessening in the amount of control education bureaucracies had on school curriculum.

Young (1971) further suggested that the writers of policy were using their own organising structures of knowledge and understanding of schools to develop curriculum policies that all schools regardless of their particular context would implement. However, schools and teachers were translating and shaping these policies to fit their local context, so the implementation of the curriculum was anything but the same across schools. This suggested that expecting curriculum policy from a system level to ensure equity and access for all was not appropriate. What mattered was the use of local contexts and experiences to build the required knowledge, skills and understanding. Although Young (1971) did not specifically discuss STEM education, his work related to the value and usefulness of programs designed at the local level compared to those designed at a system level to address issues of access and equity of access for all students. Young suggested that those programs designed and implemented at the local level would be more successful in doing so.

Young (1998), in discussing critical curriculum theory, questioned the type of knowledge included in secondary school curricula, in teacher education and in society. He described the 1990s and beyond as an era where the emergence of new technologies and globalisation had significantly changed the nature of work from a production of materials to human resource-based production and services. In this context, the concepts of qualifications, skills, knowledge and divisions between academic and vocational education and learning were changing. He suggested that there was a need to challenge the existing role and purpose of mass schooling and its organisation and move to education that mirrors the jobs in the global economic world of the twenty-first century.

Young (1998) also questioned whether specific professions require a specific knowledge base and how this is best delivered. This was against the background of government policies of the time that focussed on education programs that built skills that

were best suited to the demands of an economy predicated on global competitiveness and innovation. This is often cited in government policies as a reason for the development of STEM education programs.

Young (2007) continued to explore the purpose and type of knowledge that should be included in curricula. Schwab (2007: p.47) further argued that knowledge should lie at the heart of curriculum as opposed to skills. Young (2007) introduced the concept of powerful knowledge to re-structure the approach to the inclusion of knowledge in the curriculum and presented the concept *powerful knowledge* as combining knowledge as theory with knowledge as practice. Young (2007: p.110) suggested ten characteristics of powerful knowledge that should be considered when constructing curricula. Although Young did not specifically discuss STEM education, three of these characteristics are particularly it could be argued are relevant to what STEM education is expected to deliver. First is the acquisition of knowledge that is worthwhile for STEM and STEM related careers, employment and growing a nation's economy. Second is the provision of specialist knowledge that is needed for everyday life to provide both specialists and generalists in STEM education. Third is that all learners have access to this knowledge to become informed citizens about issues that impact on social and economic prosperity now and into the future.

Young and Muller (2016) continued to further explore the type of knowledge included in curricula and the role of curriculum in education. The challenge for STEM education is how the curriculum represents the conditions for acquiring this powerful knowledge and what it would look like from the perspective of those with an interest in STEM education. Whether this knowledge is delivered as discrete or multifaceted learning experiences requires further discussion and investigation.

Rodger Bybee (1942- ) brings a focus on progressing learning through inquiry to the development of curriculum and curriculum policy. This was evident in his contributions to the National Science Foundation (NSF), beginning in the 1980s with the development of curriculum frameworks for teaching the history and nature of science and technology for inclusion in programs for middle school science and technology and tertiary biology. Bybee also developed the *5E Instructional Model* (2009) as a lesson plan cycle which demonstrated how an inquiry approach to learning could be implemented in classrooms regardless of subject area. The model (Bybee, 2009) consisted of five phases: engagement, exploration, explanation, elaboration and evaluation.

Bybee (2010, 2013) is currently investigating the ways in which curriculum could be developed to include STEM education and the challenges its implementation presents. Bybee (2013: p.3) supported the use of contexts that emphasised drawing on knowledge of concepts and processes from across both the STEM and non-STEM disciplines to provide all students with an education that is best suited to their current and future needs. This approach it could be argued aligned with that taken by Young (1998, 2008) and Fensham (2006).

Bybee identified four dimensions (2013: pp.8-10) that he believed were necessary to implement curriculum reform that would deliver the education he saw as suitable to developing twenty-first century skills. These were the purposes or goals, curriculum policy and frameworks and, programs including resources and pedagogical practices. He argued (2013: p.73) that the implementation of STEM education was dependent on the perspective of STEM education that an educator constructed, which in turn was shaped by their experiences, situations and understanding of policies. Bybee further concluded (2013: p.80) that there was no one universal perspective for STEM education. This suggested that the existence of multiple perspectives or understandings or conceptualisations of STEM education may impact on the development and successful implementation of programs, unless those involved firstly clarify their position and reach a shared understanding as to what they expect specific STEM education programs to achieve.

Bybee (2013) has continued to investigate the quality of teaching and learning programs and a curriculum that is relevant to students. As an advocate of STEM education, Bybee is well placed to identify the challenges facing STEM education and how, with a vision and purpose, STEM education "could respond to myriad contemporary challenges" (2013: p.35).

The six selected international education researchers acknowledged that access to education should be provided to all students and that the curriculum for such an education should ensure equity of access. However, they did not always agree on the structure of the content as to how and which knowledge and skills were included in the curriculum or if it was to be system or locally developed. For example, in Huxley's *liberal education*, the emphasis was on what was to be learned as the knowledge and skills that would benefit people, whereas Dewey's emphasis was on an education that built from the experiences of the individual to better equip them for a life in their community. In contrast, Tyler focussed on the need for both generalists and specialists to provide differing levels of specific knowledge and skills. On the other hand, Young introduced the concept of a curriculum that

supported the use of contexts relevant to the students to build the required knowledge, skills and understanding.

Schwab and Bybee both supported the use of community groups working together to build a shared understanding of how to develop or reform curriculum to enhance student learning and achievement. This approach may be useful in constructing the shared understanding of what STEM education could deliver in the Australian context.

The political, economic and social environment in which each of the education researchers worked was also reflected in their approach to curriculum. For example, the nineteenth century saw advances in science knowledge and the use of technology and the increase in demand for education to be available to and accessed by more people. Working in this context, Huxley was able to garner support for a curriculum that focussed on the teaching of specific discipline knowledge and skills through experimentation and inquiry. The early twentieth century saw a continued emphasis on providing education to more young people within the context of moving towards a more progressive and mobile society. In this context of social change, Dewey's approach that focussed on the development of curriculum that educated each person to become an active and responsible participant in their community was gaining prominence.

Tyler was working on curriculum at a time when the USA and the USSR were competing in the *race to conquer space.* In this environment, the political influence was strong and saw funds invested in education in the USA to produce the skilled personnel required to win this race. In this environment, Tyler was able to design a curriculum that focussed on learning as being the achievement of specific behavioural objectives or outcomes. This led to the introduction in secondary education programs of specialist areas such as physics, chemistry and advanced mathematics that required a higher level of knowledge and skills. It was believed that this would cater for the most able and interested senior secondary students and encourage them to continue their studies to become the required specialists and technicians. The other secondary students would be able to study generalist science and mathematics subjects which it was believed would enable them and their community to understand the benefits of and support the high levels of spending on the space program.

Schwab was working at a time when discussions about who should be responsible for the development, review and revision of curriculum were prominent, as more young people

from diverse backgrounds were beginning to attend secondary schools. To cater for this increased enrolment, Schwab pursued research that sought to reconceptualise teaching at all levels and defended the re-establishment of a liberal education as suggested by Dewey.

Young explored the type, delivery and acquisition of knowledge that was inclusive of the needs and interests of all students. Young introduced the concepts of powerful knowledge and professional knowledge at a time that favoured education programs that built a set of generic skills suited to the demands of an economy predicated on global competitiveness, innovation and social prosperity. In so doing he illustrated the importance of the relationship between knowledge and skills and that the usefulness of these to the learner mattered and should be reflected in government policies related to education including curriculum.

Bybee, like Schwab and Young, was interested in what learning was occurring during the time a more diverse group of students entered school. Bybee suggested the use of inquiry-based learning experiences relevant to the learner would build their understanding and skills and engage all students in learning regardless of their background. As the political and economic environment shifted its focus to the acquisition of skills for the jobs of the twenty-first century, Bybee also proposed that the curriculum should include activities where the learner is engaged in solving a problem or researching an issue and uses evidence to develop a solution or explanation. Bybee suggested that this would support the learner to develop, use and refine the skills necessary to grow the nation's economy in the twenty-first century. Bybee developed the *5E* model to assist teachers cater for the individual needs of their students within an increased emphasis of accountability for improved student outcomes. This model encouraged teachers to consider curriculum, pedagogy and assessment as a collective when planning programs, as Young had also suggested.

### 2.2.3 The selected Australian education researchers with expertise in curriculum

Three Australian education researchers were selected using the same selection criteria as those used to select the six international education researchers. These were Peter Fensham, (Robert) Garth Boomer and Russell Tytler. These education researchers offered expertise in the design of curriculum and assessment and pedagogical practices and experiences in the development and implementation of policies and programs related to education at the national and international level.

Peter Fensham (1927-) is a prominent and respected curriculum theorist and researcher in science education and curriculum in Australia and internationally. Fensham argued (1985)

that a recognition of the importance of a general science education for all students, not just to provide future specialists, was required and would provide a vision for future curriculum developments in science.

Fensham (1985) suggested that the previous science curriculum catered for the twenty percent of students who were likely to become the science specialists. Fensham further argued that the *Science for All* approach to science curriculum could cater for these students as well as the other eighty percent, if a holistic approach to teaching and learning in science was adopted. Fensham also argued strongly for a program where science as a life experience is provided in primary schools, general science is provided in lower secondary years and specialised science streams, including in vocational training, were available in the upper secondary years. Fensham (1985) suggested that both the content of the science curriculum and the pedagogy employed in the classroom need equal consideration if this approach is to succeed. Some aspects of his recommendations are visible in the three strands of the Australian Curriculum science learning area. These strands are designed to be considered together when planning learning experiences and assessment tasks for all students from F (foundation or first year at primary school) to Level 10 (or Year 10 in secondary school). In the early primary years of schooling, the focus of the curriculum is building students' curiosity and interest in the science visible in their world. From the upper primary years to Year 10, the focus of the curriculum is on understanding specific concepts, processes and practices in specific substrands of science, for example, biological sciences and earth and space sciences. It could be argued that this science curriculum moves from a general science approach for the younger students to a more highly specialised science approach for the older students.

In maintaining the specialist science subjects and a more inclusive general science subject, it could be argued that Fensham has referenced the work of both Huxley and Tyler. By considering both content and pedagogy, Fensham shared an approach to curriculum similar to that of Dewey, Young and Bybee.

In looking to the future of the science curriculum, Fensham (2006) opined that predicting future directions for curriculum development without considering the political, economic and societal contexts of the jurisdictions and systems was problematic. Fensham proposed (2006: p.169) that future directions in science curriculum should place schools and science classes at the centre. Fensham further argued, that this would allow for the inclusion in the curriculum of newer directions, for example, a humanistic approach and a context-

based approach that supported building scientific literacy and offered the flexibility required to include new developments in science. Opponents of this approach argued that such a curriculum lacked sufficient specification of content knowledge and skills so that measuring student achievement and progress would be difficult. Fensham (2006) argued that this focus on science knowledge was reminiscent of the 1960s approach where the transmission of content often organised in topics took precedence over pedagogy.

Fensham (2016) further argued, that the most promising future directions for science curriculum would focus on the development of science and its use and influence. Fensham also suggested that the success of this approach would require the provision of examples of high-quality teaching and learning and assessment that moves beyond memory and recall and values applications, reasoning and decision making.

(Robert) Garth Boomer (1940-1993) was a senior education bureaucrat for the Commonwealth of Australia and South Australia at a time when equity and access to education were at the forefront of discussions related to the education of young Australians. His work was influential in informing and shaping education policy, curriculum and teaching through a series of essays related to curriculum and teaching in Australia and negotiating the curriculum (1992: pp.4-13). Boomer adopted a pragmatic-radical position, where he acknowledged the impact of the prevailing economic conditions on funding education while continuing to advocate for social justice, equity, and educational reform. Boomer was also an advocate for teachers undertaking research into their practice to develop new insights that would inform and improve their teaching. Boomer (1992: p.4) presented curriculum development "as a critical and reflective process, responsive to student needs and priorities".

Boomer believed that curriculum development included pedagogy and assessment, as illustrated in his essays (1992) where he provided a chronicle as to how curriculum had changed in Australia since 1960. Boomer further argued that the gap between the published curriculum and the enacted curriculum practised in schools had become progressively wider. Boomer argued (1992) that although there had been changes in the curriculum documents during this time, for example in the introduction of specialist sciences and mathematics, little attention had been given to changing pedagogical practices despite the burgeoning number of students enrolled in schools.

Boomer (1992: p.30) categorised the 1960s as the beginning of change where new subjects were added, the 1970s as expanding choices and the 1980s and beyond as

emphasising accountability. Boomer also believed that curriculum was gradually moving towards competency-based assessment outcomes and the notion of essential knowledge to address issues of retention and inequities in participation due to gender, ethnicity or socio-economic status. Boomer (1992) further suggested that educators focussed on *Dewey type* skills whilst industry and trade unions focussed on a curriculum that considered the demands and realities of work. This highlighted the difference between the outcomes of education as expected by different stakeholders in with an interest in curriculum and education. Boomer also sounded a warning that is applicable to STEM education given expectations of the diverse stakeholders:

> it is important that the best and most subtle curriculum thinkers find a way to re-enter the debate in an attempt to offset the worst effects of vested interests, particularly those with narrow, shallow economic goals. (1992: p.133)

Boomer (1992) suggested that the re-construction of Australian industry was leading to a constructivist approach to education. Boomer also argued, like Fensham (1985), that this would require a new or fresh pedagogical approach. He acknowledged that teachers would be reluctant to change their current practice unless ongoing professional development and new resources were provided. He also recommended that curriculum documents and policies should be consistent and presented in language that was accessible and meaningful to teachers.

Boomer (1992: pp.139-140) suggested that educationally based and explicit benchmarks should be accepted and valued by all interested in education. Such benchmarks should be capable of shifting from norm-referenced to criterion referenced to standards as the direction of curriculum policies and education reform evolved. Boomer believed:

> We need all our young people to learn technologies and various media so they can with confidence make things work … be engaged (in small groups) not the factory model of past (schooling). (1992: p.140)

It could be argued that although written in the 1990s, this statement is relevant to STEM education in the Australian context as it suggested that providing relevant and engaging experiences for students would assist them adapt to new or changing employment opportunities.

Russell Tytler is an internationally respected science educator and researcher. Tytler also suggested, like Fensham, that students would be better engaged in science if the

approach to curriculum development and pedagogical and assessment practices were reformed. Tytler was also concerned about the declining enrolments in specific science disciplines and students' negative attitudes towards science subjects. Tytler (2007) believed that there was a crisis in science education, that had been initiated by a massive disconnect between the science presented in schools, contemporary science and what matters to young Australians. This crisis was then visible in the declining uptake of a careers in science related industries. Tytler (2007) introduced the concept of *re-imagining science* as the way to deal with this crisis and suggested that scientific literacy could be the focus for driving change in school science (as suggested by Hackling, Rennie and Goodrum 2001).

Tytler argued:

> What is needed is a re-imagining of science education that involves a re-thinking of the nature of science knowledge dealt with in schools, moving away from authoritarian knowledge structures to more flexible, and more challenging, conceptions of classroom activity and more varied ways of thinking about knowledge and learning. (2007: p.67)

Tytler (2007) then proposed that a coherent national vision and future directions for science education are urgently needed if Australia is to capitalise on and promote further innovation in science and science education. A focus for this re-imagining of science would in part be based scientific literacy within a flexible, contemporary and challenging curriculum supported by high-quality assessment practices. A sustained program of professional learning would be required to build teacher capacity to implement this re-imagined science curriculum and associated assessment practices. This suggested that a vision for STEM education in the Australian context could be developed that is consistent with government policies. An investigation as to how the programs developed to implement this vision would be inclusive of different pedagogical practices and how these would maintain the inherent integrity of each discipline would be beneficial.

Fensham and Tytler drew from and referenced the work of each other in identifying where improvements in education and science education were needed and in providing suggestions as to how these may be addressed. The work of Fensham, Boomer and Tytler suggested that factors that have influenced the development of science curriculum were like those that influenced the whole curriculum. It could be argued that understanding the context in which previous attempts to reform science curriculum in Australia were undertaken, how successful outcomes have been maintained and being cognisant of any barriers to achieving

success would be beneficial in informing the curriculum and associated pedagogy and assessment required to implement of STEM education.

Fensham, Boomer and Tytler all emphasised the importance of the provision of specific professional development programs for the successful implementation of curriculum reforms. Current Australian governments also have a focus on increasing student achievement and outcomes through improving the quality of teaching and learning to achieve economic growth.

### 2.2.4 Conclusion

All the selected education researchers acknowledged the need for students to access education that was relevant to them and supported a collaborative approach to curriculum development and implementation. However, they did not always agree as to the type of knowledge and skills to be included in the curriculum or how the curriculum should be structured or how student progress and achievement should be assessed or the most appropriate pedagogy or assessment practices to support the implementation of the curriculum. However, they did support a collaborative approach by all those involved to the development and implementation of curriculum.

## 2.3 Constructing the Curriculum development framework

### 2.3.1 Introduction

The selected education researchers have worked in and across different political, economic and social contexts which was reflected in their approach to curriculum development and implementation. This suggested that a curriculum development framework from a historical perspective suitable to underpin this study would include distinct phases that reflected the changes in the political or economic or social contexts that impacted on all aspects of education.

In deciding on the use of a curriculum development framework the following were considered:

- the work of the selected education researchers;
- the political, economic and social contexts in which the focus of curriculum changed;
- the prominence given to science in STEM education policies and programs;
- the previous curricula imported for use in Australia.

Australia has in the past used (or adapted for use) science programs from the USA, for example PSSC Physics (Physical Science Study Committee, 1960-1970s) and from the UK, for example, The Nuffield Science Teaching Project (Nuffield Foundation, 1960s-1970s). This led the to the consideration of published curriculum development frameworks for science from the USA (DeBoer, 2014 and Schiro, 2008) and from the UK (Kelly 2009). The curriculum development framework for science from DeBoer (2014: pp.559-578) was considered appropriate for this study for the following reasons. First it was published in the in the Routledge *Handbook of Research on Science Education* which is an internationally recognised reference work. Second was that one of DeBoer's many research interests is in clarifying the goals of the science curriculum which parallels building an understanding of what of STEM education in the Australian context could look like and deliver. Third was his role as Deputy Director of Project 2061 (AAAS, 1985) which is:

> A long-term initiative of the American Association for the Advancement of Science (AAAS) to help all Americans become literate in science, mathematics, and technology.

and includes three of the disciplines included in STEM education.

This framework consisted of five distinct phases of curriculum development which could be aligned to the contexts and the work of the education researchers selected in this study and which are applicable to curriculum in general not just science.

Whilst a year for the commencement of each of the five phases is given, the end date is not specified because elements of the preceding phase were still present in succeeding phases. Also beginning before 1850 was thought not to be relevant to this study given the small population and the limited provision of and access to formal education in the very early years of European settlement in Australia.

### 2.3.2 The phases of curriculum development

Empiricism (1850- )

In this phase of curriculum development, there was a focus on performing laboratory work using observations to find patterns and new relationships, with scientists directing the development and content of curriculum. Paying attention to student interest was also encouraged. Supporters of this approach included prominent scientists like Thomas Huxley, Herbert Spencer and William James.

It could be argued that if the curriculum for STEM education was to reflect the empiricists' rationale of learning through doing and replicating the outcomes of experiments, then their focus on providing opportunities to build a required skill set is consistent with the drive for a STEM skilled workforce as evident in policies such as the *National STEM School Education Strategy. A comprehensive plan for Science, Technology, Engineering and Mathematics Education in Australia* (2016-2026), (2015) and the *STEM 2026: A Vision for Innovation in STEM education*. USA (2016).

Progressivism (1901-)

In this phase of curriculum development, the focus was on the social relevance of education as distinct from the education for the workplace. As such, the learning experiences presented to the students drew on their interests and that of their local community. Whilst retaining the practical focus of the empiricists in developing skills was retained, new applications presenting science as technology were included to reflect the expansion in knowledge and modern inventions, for example, aeroplanes, automobiles and radio. The use of textbooks in the classrooms to support student learning was also emerging. Educators such as John Dewey and Robert Bradbury were now advocating for curriculum development to include direct links between areas of learning.

It could be argued that joining or integrating the different areas of learning, for example, science and technology pointed to the interdisciplinary nature of STEM education. Publications such *VicSTEM Science, Technology, Engineering and Mathematics* (2016) and *Conceptualizing Integrated STEM education* (Johnson, 2013) discussed the possibilities for an interdisciplinary and integrated approach to STEM education.

Nature of Science (1950- )

In this phase of curriculum development, the focus was on current and scientifically correct curriculum with an emphasis on building scientific knowledge through the individual disciplines of science and the use of scientific investigation. This phase saw the development of specific discipline-based programs in physics, chemistry, biology and mathematics and understanding why scientists used a specific approach, for example, the empirical testing of a hypothesis to solve problems. The race to conquer space and *Sputnik* focussed the attention on the contribution of science to society. The curriculum became a vehicle to build specialist knowledge in science and mathematics. This was a shift away from the approach of the Progressivism phase that favoured a more general curriculum that drew on students' actual

experiences. Unlike previous curriculum reform, cognitive psychologists were now contributing to the development of curriculum and provided a focus on learning, memory and thinking. Bodies such as the National Society for the Study of Education and the American Chemical Society were prominent advocates of this approach to curriculum development.

It could be argued that when the curriculum for STEM education is organised in separate and specialist areas of knowledge it adopts a silo approach where each of S, T, E and M operates as a separate entity rather than as being interdisciplinary or integrated. In the current Australian Curriculum science, mathematics and technologies (including design and technologies and digital technologies) are presented as separate learning areas. However, to avoid this silo like approach, the current Australian Curriculum also identified the general capabilities, for example, numeracy, information and communication technology, critical and creative thinking as integral components of STEM with engineering design and processes addressed in the technologies.

Neo-progressivism (1970- )

This phase of curriculum development was often referred to as the return of a social conscience because it emphasised the equality of educational opportunity. To achieve this, the curriculum content would be accessible to and inclusive of students who had previously not pursued education beyond secondary school due to location or disability or race or gender or socio-economic status. This was achieved by making science relevant for all students through a shift in emphasis from specialist science knowledge to a more general science knowledge and the use of different pedagogical approaches. Like the first fifty years of the twentieth century, curriculum development was now being driven by personal and social relevance and attention to student interest. Educators such as Roger Bybee, Diane Ravitch and Peter Fensham were key supporters of this phase of curriculum development. In a sense the Neo-progressivism phase was updating or building on the earlier Progressivism phase to better reflect the social, political and economic environment of the times.

Similarly, STEM education emerged in response to the specific and contemporary concerns about growing the nation's economic prosperity within changing and challenging global markets and future careers and jobs. The content of the curriculum and the STEM education programs would be expected to reflect this. The term *race* has since been replaced with ethnicity or indigenous or first peoples in education publications.

Standards-based reform (1990- )

In this phase of curriculum development, the desire of governments to respond to declining student performance on international tests and the loss of economic competitiveness is a prominent driver of the content included in curriculum. In this environment, education is also expected to address inequities in student outcomes. The curriculum contains an accountability framework with achievement standards for all areas included. These standards systematically and directly linked knowledge and skills or content statements to assessment of student achievement. Unlike the previous phases, the curriculum was now organised and managed through learning experiences directly linked to the standards, assessment and appropriate pedagogy. Governments, business and industry were now directing the education policies and the curriculum using slogans like *equipping students with skills for the twenty-first century*. The origins of the standards movement to curriculum development can be traced to The National Centre on Education and the Economy (NCEE), a policy analysis and development organisation based in Washington, D.C. USA. The publication in the USA in 1983 of *A Nation at Risk* also provided the impetus to include accountability for improved student achievement and outcomes in education policies related to curriculum.

A detailed analysis of the curriculum development framework and its relevance to this study is included in 7.3 and 7.6.

## 2.4 Relevance of the curriculum development framework to STEM education in the Australian context

### 2.4.1 Introduction

In discussing STEM education Chubb (2013a) and Johnson (2012a), identified a skill set that they believed was necessary to equip people to actively participate in and contribute to a STEM skilled workforce.

Current government STEM education policies internationally and in Australia are focussed in part on developing a STEM skilled workforce with transferrable skills, enabling workers to move seamlessly from project to project or to different employment settings. These policies include sections with targets and funding related directly to school education and as such have had significant impact on the shape of curriculum development.

However, what was not included or specified was the STEM knowledge required or expected to be developed and how this would support the acquisition of these STEM skills or

how this knowledge was selected or organised. The curriculum development framework discussed earlier in this chapter assisted with identifying how knowledge was presented in each phase of the framework and how this was relevant to STEM education including supporting the acquisition of specific skills. This is shown in the tables below.

Although each phase of curriculum development emerged in response to the social, economic, political environment that existed at a time, it did not completely replace the phase that preceded it. Rather the emerging curriculum was layered with features from the previous phase that were retained.

### 2.4.2 The inclusion of knowledge

The structure and organisation of the science, mathematics and technologies learning areas in the Australian Curriculum are very similar. The science learning area was used as an example to show the link between each of the phases from the curriculum development framework to the knowledge included in the Australian Curriculum and the possible implications for STEM education. This information is presented in Tables 2.1, 2.2, 2.3, 2.4 and 2.5.

**Table 2.1 Possible implications for STEM education in the Australian context from the inclusion of knowledge in the Empiricism phase.**

| Underpinning philosophy of the phase of curriculum development | Description of the type of knowledge in the AC Science learning area | Possible implications for STEM education |
|---|---|---|
| Building science knowledge and understanding through doing and using skills to make observations to produce credible and reliable results. The scientist as the expert guided and directed the learning of the students through the provision of a specific curriculum. | Developed and generated by testing theories and explanations through experiments, where new ideas were checked, directly linked to the application and acquisition of knowledge and skills. | The development of knowledge occurred in a context that required knowledge to produce understanding and competence. |

**Table 2.2 Possible implications for STEM education in the Australian context from the inclusion of knowledge in the Progressivism phase.**

| Underpinning philosophy of curriculum development | Description of the type of knowledge in the AC Science learning area | Implications for STEM education |
|---|---|---|
| Educating the whole person beginning with their interests to develop the knowledge and skills required contribute to their community. The focus was on the learner with the teacher responsible for the provision of opportunities that progress the learner's understanding and skills development. Allowed the teacher to exercise professional judgment as to how to structure the learning to reflect the interests of the individual. | Presented as integrated across areas in a purposeful and meaningful way that engaged the learner in and with the process of acquiring knowledge and skills. | Provision of contexts for learning that were relevant to the individual and would best prepare them for life as the mature adult. |

**Table 2.3 Possible implications for STEM education in the Australian context from the inclusion of knowledge in the Nature of Science phase.**

| Underpinning philosophy of curriculum development | Description of the type of knowledge in the AC Science learning area | Implications for STEM education |
|---|---|---|
| Building specialist knowledge in science and mathematics, including skills development in an approach to scientific investigation. Focus of learning was to acquire the knowledge and expertise to understand the contribution of science to society as determined by education experts in curriculum design. Provided the teacher with a sequence for learning that included what was to be taught when and a set of resources including textbooks to facilitate the process of learning. | Organised and presented in separate specialist disciplines for example, chemistry, physics and pure mathematics. | Recognition that the disciplines have specialist knowledge and approaches to investigations including skills that could be presented in a context or integrated or as a separate entity. |

**Table 2.4 Possible implications for STEM education in the Australian context from the inclusion of knowledge the Neo-progressivism phase**

| Underpinning philosophy of curriculum development. | Description of the type of knowledge in the AC Science learning area | Implications for STEM education |
|---|---|---|
| Providing the same educational opportunities to all students to address disadvantage. A reduced focus on specialist content and an increased focus on how meaningful learning best occurred. Encouraged the teacher to focus on pedagogical practices that supported the learning and addressed the needs of individual. | As a set of basic concepts that all students accessed, often focussed around caring for the environment. | The need for approaches to teaching and learning that were inclusive of and engage all students. All students were provided with enough opportunities to develop STEM skills in multiple contexts. |

**Table 2.5 Possible implications for STEM education in the Australian context from the inclusion of knowledge in the Standards-based reform phase**

| Underpinning philosophy of curriculum development. | Description of the type of knowledge in the AC Science learning area | Implications for STEM education |
|---|---|---|
| Accountability for student outcomes through the achievement of a set of standards across the curriculum. Focussed on the acquisition of specific skills to support economic and social prosperity. The teacher presented students with a sequence of learning experiences that would enable them to demonstrate levels of achievement against the standards. | As a set of knowledge or content statements that were directly linked to corresponding achievement standards. | Knowledge statements and assessment tasks that were relevant and meaningful for the students and allow them to demonstrate achievement of the standards. |

Exploring the role of knowledge as well as skills in STEM education focusses attention on two important questions raised by Young (1998). Firstly, whose knowledge is being or should be included and secondly, was who chooses the knowledge to be included?

For the Empiricism and the Nature of Science phases of curriculum development, the answers to both questions are very similar. Experts external to the schools prepared and organised the curriculum and assessment tasks for the teachers. The experts included what they believed was relevant for students to know, be able to do and achieve. However, as Fensham argued (1985), such an approach to curriculum development would not cater for the needs of all students.

For the Progressivism and Neo-progressivism phases of curriculum development, the answers to these questions are problematic. It could be argued that providing a variety of contexts drawn from the learners' interests meant that both the teacher and student were exercising some level of choice over what knowledge was important. The teacher by presenting a specific context or set of contexts through which the students would acquire knowledge has by default chosen the knowledge that the students were expected to acquire. If each student chooses the context for their learning there is a possibility that this choice could limit their opportunities to participate in further education and employment that required different knowledge. Also, decisions about what students know, what they don't know and

what they need to know are dependent on and can be influenced by the teacher's past experiences and their perceptions of the students.

For the Standards-based reform phase of curriculum development, the knowledge included has been chosen by governments, business, industry, universities and further education authorities and education bureaucrats and is designed to deliver specific outcomes for students. Schools and teachers are responsible for providing enough learning opportunities that will enable all students to achieve the expected outcomes.

Young (2008) suggested that there were two types of knowledge, one developed through a formal, general education that was important for all citizens to have and one developed through participation in a specialist or technical profession or through employment on a work site. It could be argued that these two types of knowledge can be included in STEM and fit with the phases of the curriculum development framework used to underpin this study. STEM knowledge developed from a generalist education would be reflective of the approach to knowledge development from the Progressivism and Neo-progressivism phases. Education that focussed on the development of specialist or technical knowledge would be reflective of the Empiricism and Nature of Science phases. A set of achievement standards that expected students to demonstrate general and specialist knowledge in STEM would be reflective of the Standard-based reform phase.

### 2.4.3 Which of the STEM skills are included in the Australian Curriculum?

STEM skills are often presented as supporting the acquisition of required knowledge including a demonstrated capacity or competence in critical and creative thinking, problem solving, team-work, collaboration and co-operation, flexibility and adaptability and ethical behaviour (Chubb 2013a, Johnson 2012a). These are similar to the general capabilities (Gcs) included as an integral component of the Australian Curriculum.

In the Australian Curriculum, the STEM skills are included in three learning areas and the general capabilities. STEM skills are included in the science and mathematics learning areas, in the Science Inquiry skills strand and in the Understand how Mathematics work strand respectively. In the Technologies learning area, STEM skills are included in two strands, Design Technologies Processes and Production skills and Understand Digital Processes and Production skills.

The Gc Numeracy includes STEM skills related to using measurement, estimating and calculating with whole numbers, recognising and using patterns and relationships, using

fractions, decimals, percentages, ratios and rates, using spatial reasoning and interpreting statistical information.

The Gc Information and Communication Technology (ICT) includes STEM skills related to investigating with ICT, creating with ICT and communicating with ICT.

The Gc of Critical and Creative Thinking includes STEM skills related to reflecting on thinking and processes, inquiring as identifying exploring and organising information and ideas, generating ideas, possibilities and actions and, analysing, synthesising and evaluating reasoning and procedures.

In the Australian Curriculum there is not a specific learning area for engineering. Instead it suggests:

> Engineering is addressed in Design and Technologies through a dedicated content description at each band that focuses on engineering principles and systems. It is presented across the curriculum through Science, Digital Technologies and Mathematics. (2019)

To support teachers to include STEM education, ACARA published annotated work samples where STEM education is presented as being interdisciplinary and also provided the following information:

> The interdisciplinary nature of STEM in these projects is evident. While annotations for work samples have been identified as one or other of the Australian Curriculum STEM learning areas (Science, Technologies, Mathematics), it is important to note that the skill is often developed in all three. As engineering is addressed across the curriculum through Science, Technologies and Mathematics and in a dedicated content description focusing on engineering principles and systems at each band in Design and Technologies, content relating to engineering is identified under the most appropriate Australian Curriculum learning area for each project. (2019)

In Australia, Prinsley and Baranyai (2015) undertook an investigation of the skills and attributes employers valued in workplaces in STEM or STEM related areas. Prinsley and Baranyai (2015) constructed a list of occupation-specific STEM skills that they believed were addressed in the specific learning areas and general capabilities of the Australian Curriculum as discussed above. Prinsley and Baranyai (2015) also found that employers ranked highly interpersonal skills, understanding how business and industry work, time management and lifelong learning. These are included in the general capabilities of Personal and Social, Intercultural Understanding, Ethical Understanding and Literacy.

The Australian Curriculum has accommodated STEM education in a unique way through a combination of the learning areas of science, mathematics and technologies, the general capabilities and the provision of annotated work samples as examples of STEM education tasks and projects. These work samples showed how STEM education programs in the Australian context could be developed and implemented. This approach was designed to provide learning experiences that are of interest to all students and to meet the expectations of governments, business and industry and the community. Engineering has not been included as a separate learning area in the Australian Curriculum, but rather was addressed in the existing learning areas of science and mathematics and technologies.

## 2.5 The introduction and implementation of STEM education in the United States of America (USA)

### 2.5.1 The introduction of STEM education

During the 1990s, numerous national commissions and inquiries continued to call for *instructional innovations in science, mathematics, engineering and technology* which became known as SMET education. The National Science Foundation (NSF) began to use the acronym STEM in the place of SMET in the late 1990s and in 2000 used STEM education. The NSF (2007) believed that improving science and mathematics education in the USA was essential and noted that many reports, dating from the 1980s, had focussed on the quality of science and mathematics education, including the advocacy of scientific literacy as part of Science for All Americans (AAAS 1989). The publication of the report Rising Above the Gathering Storm (NAP 2007) also galvanised support for the importance of STEM education and its role in assisting the USA to increase economic growth and sustain a competitive advantage in global trade by improving mathematics and science education.

The introduction of STEM education in the USA also provided an opportunity to improve student achievement on national and international tests and to provide the knowledge and skills workers would require as the types of jobs and employment changed due to the rapid advances in technologies. In this context the responsibility of STEM education was to drive economic and social prosperity in a changing and challenging global environment as part of governments' political agenda.

### 2.5.2 Implementation of STEM education in the USA

With the acceptance of STEM education, attention turned to research that would identify the factors and requirements that could influence its implementation in different education settings, including a focus on how engineering as a discipline with its specific knowledge, skills and practices would be included in the programs.

The implementation of STEM education programs in tertiary education has gained interest and momentum in response to USA government policies and statements from business and industry related to the supply of the required and suitably trained STEM skilled workforce. Henderson, Beach and Finkelstein (2011) undertook a study that reviewed the different types of research being undertaken in higher education that focussed on changing current practices to deliver STEM education. Henderson et al. (2011) found that there were three different types of research related to STEM education being undertaken. First was Science Education Research (SER) which focussed on writing discipline-specific activities providing best practice to change individual educators' approach to curriculum and assessment. Second was Faculty Development Research (FDR) which focussed on the general improvement in the pedagogical practices of all the educators. Third was Higher Education Research (HER) which focussed on changing the environments and structures to provide greater access for students to courses rather than changing individuals' practices.

Henderson et al. (2011) also found that these types of research within the same institution tended to operate more of less independently of each other, with their own distinct perspectives and strategies related to change. Henderson et al. (2011) further suggested that a shared vision or understanding or conceptualisation of what was required for a coherent undergraduate program in STEM education had not been discussed or given a high priority. Henderson et al. (2011) argued that this lack of coherency could possibly provide the students with different or even conflicting ideas about STEM education and its implementation. The findings from Henderson et al. (2011) also suggested that, when investigating STEM education and its implementation, it was important to include relevant programs in higher education.

Interest in the implementation of STEM education in tertiary education has led to research into what happens in STEM and STEM related fields beyond universities. In this context, Breiner et al. (2012) undertook research to determine how STEM was understood by those working in STEM and STEM related areas. The research included members of a public

research institution. Breiner et al. (2012), like Henderson et al. (2011), found that there was not a shared conceptualisation of STEM education amongst the people they interviewed and that the person's conceptualisation was linked closely to their discipline. This was evident in their findings related to their participants' attitudes to STEM education where those from non-STEM areas were more likely to have a negative attitude to STEM education and those from STEM areas were either positive or neutral.

Breiner et al. (2012) believed that the differences in people's conceptualisation of STEM education were due to the existence of three types of conceptualisations. These were Educational Conceptualization, Political and Societal Conceptualization and Personal Conceptualization.

*Educational Conceptualization* was described as the use of an integrated approach to STEM education to reflect the transdisciplinary nature of problem solving being enacted in STEM related industries. As such this is more reflective of the Neo-progressivism approach to curriculum development with its focus on solving real-world problems. This approach runs counter to what has been the traditional approach of developing highly specialised knowledge and skills within a discipline which was more reflective of the Nature of Science approach to curriculum. Breiner et al. suggested that if an integrated approach to the implementation of STEM education is to be more widely adapted, a change in people's conceptualisation would be required.

*Political and Societal Conceptualization* was described as the use of data and funding to drive and increase students' interest and participation in STEM education and for a specific outcome such as increased rankings on international tests. For example, if the published curriculum, assessment tasks and the pedagogy predominantly retained the silo approach of separate disciplines as in the Nature of Science approach to curriculum development, then the opportunity to introduce the integrated nature of STEM practices that industry and research are using will likely be missed. The students would then have limited experience in investigating and solving real-world problems that require drawing on and connecting relevant knowledge from the STEM disciplines. Breiner et al. (2012) commented that a further complication was the politicians' understanding of what STEM education offers and how it should be implemented. Breiner et al. (2012) also suggested that the politicians' level of understanding impacted directly on the setting of priorities for funding allocated to STEM education programs, initiatives and research and the setting of targets to demonstrate the achievement of the intended outcomes of published curriculum policies.

*Personal Conceptualization* was described as the general agreement by those working together in partnerships that it was important to increase STEM literacy and equity of access to opportunities in STEM education for all students. However, what this agreement would look like and how it is achieved depends on the context and those involved in the partnership. Breiner et al. (2012) argued that building an understanding of STEM education and how best to implement and deliver STEM education should be a priority for the members of the partnership. Any disconnect between the understanding of any of the stakeholders as to what STEM education is or how to implement it is likely to impact negatively on the intended outcomes. This is particularly true of how people understand what an integrated curriculum for STEM education would look like and how this would be beneficial for its implementation. In constructing a personal conceptualisation of STEM education, stakeholders are using their experiences and positions. Breiner et al. (2012) suggested that although it is unlikely such personal conceptualisations of STEM education will be the same, there will be some similarities amongst the differences.

Breiner et al. (2012) found that most stakeholders agreed that STEM education was necessary to provide students and the workforce with the knowledge and skills required to ensure the nation's continuing economic prosperity, innovation and global competitiveness. It could be argued that this is the beginning of a vision statement from which strategic policies could be written to achieve the intended outcomes of STEM education. Breiner et al. (2012) also suggested that using plain and accessible language in such policies should help to limit the disconnect between stakeholders and enhance the successful implementation of STEM education.

It could be argued from the research of Breiner et al. (2012), that the context determines and influences people's conceptualisation of STEM education. Breiner et al. (2012) suggested that due to these differences, a concise operational definition for STEM education would be almost impossible to achieve. Breiner et al. (2012: p.9) proposed instead that establishing shared outcomes for STEM education between stakeholders is where effort should be expended. Breiner et al. (2012: p.10) further suggested that a one-size-fits-all approach to implementing STEM education is unlikely to be productive and argued that best practices and initiatives should be shared widely among all stakeholders, fostering a culture of collaboration focussed on achieving better outcomes for all students.

In discussing how to best implement STEM education and how it will look in different settings, Johnson (2012b) suggested that it was essential to better understand STEM

education and what it offers before advocating for a specific approach for its implementation. Johnson (2012b) focussed on what needed to be done and how this could be achieved in a way that will benefit all in the community and presented four premises that supported the implementation of STEM education. It could be argued that these four premises may also be applicable to the implementation of STEM education in the Australian context.

First Johnson (2012b) argued that implementing STEM education represented an opportunity to integrate content across the disciplines in a natural way that was consistent with what happens in the real-world where solving a problem is reliant on drawing together the knowledge from all disciplines regardless of whether the problem solver is a scientist, engineer, mathematician or technologist. This represented a paradigm shift from teaching in silos to using an integrated approach, one that past attempts at integration such as Science Technology and Society (STS) had not achieved. An integrated approach required that students had access to the knowledge they required to solve a problem regardless of their experience.

Second Johnson (2012b) emphasised that all students needed experiences in STEM education not just those with high ability levels in the STEM disciplines.

Third Johnson (2012b) believed that it was essential to upskill teachers in pedagogical practices and the curriculum content of the STEM disciplines so that they could successfully implement STEM education programs. Johnson argued that funding ongoing teacher professional development without a commitment from teachers to keep up to date with new innovations and techniques was not enough to ensure that the current and future needs of their students were being met. The Victorian Government's *VicSTEM* (2016) publication likewise emphasised the importance of ongoing professional learning for teachers in the successful implementation of STEM education that met the government's expectations.

Fourth Johnson (2012b) maintained that without an alignment of vision, strategies, implementation, evaluation and accountability in STEM education policies at the federal, state and local levels, its implementation would not be a priority. Johnson (2012b) also believed that the emphasis on improving student achievement in mathematics as a stand-alone discipline would likely remain the dominant priority in the USA and limit the implementation of integrated STEM education.

Johnson (2012a) conducted research into the implementation at a regional level of an educational STEM partnership and the establishment of STEM schools. Johnson (2012a) also

argued that the lack of a cohesive strategic plan and trying to concurrently implement both a partnership and STEM schools limited the successful implementation of either initiative. It could be argued that Johnson's research provided an example of how a misalignment between the needs and understandings of the stakeholders and STEM education policies can impact on the expected outcomes of a program and was consistent with the suggestions made by Breiner et al. (2012).

It could also be argued that Johnson's research (2012a) provided five pointers as to what would be required for the effective implementation of STEM education in Australia. First was the need for a shared vision that is understood by and has meaning for all stakeholders which was consistent with a suggestion from Tytler (2007).

Second was the development of a set the immediate, short and longer-term goals for the implementation of STEM education and the need to move beyond the electoral cycle for governments. Such a plan should include a shared vision for the implementation of the program and the roles expected of all stakeholders. It should also acknowledge that embedding worthwhile educational change takes time and resources.

Third was collaboration between stakeholders that was evident in ongoing shared ownership and responsibility for the implementation and evaluation of STEM education programs, progress to ensure all students have access to STEM experts and workplaces.

Fourth was the existence of strong leadership and advocacy at all levels to maintain a profile for STEM education within the community to support innovation, celebrate achievements and garner resources as required. This would include ensuring that professional learning was provided to all stakeholders as and when required.

Fifth was stating explicit accountability measures to provide outcomes against which progress can be measured and demonstrating to the community that the outcomes are both beneficial and cost effective.

Johnson (2013) noted that although STEM reform in the USA began at the federal level, stakeholders at the state and local level were able to pursue the reforms in their own ways. Johnson (2013) further argued that this has led to multiple meanings for STEM education and a variety of programs for its implementation. Johnson (2013) also identified two models that she believed underpinned the structure of these programs. These were the *STEM enhanced* model and the *integrated STEM* model. Johnson (2013) also indicated a strong preference was for the *integrated STEM* model (2013: p.367 and argued that the STEM enhanced model

prevailed in most current programs in the USA because it allowed schools to still focus on mandated assessment and accountability. This model provided experiences in STEM education as elective programs that students could choose to study. These were presented as additional stand-alone programs in science, technology, engineering and mathematics or as new or additional assignments with an interdisciplinary focus. Johnson (2013) also believed that at best these programs would have a limited or tenuous connection to the core curriculum.

Johnson (2013: p.367) argued that the integrated STEM model would provide a more desirable and authentic approach as it was more than simply combining two or more of science, technology, engineering and mathematics. Johnson saw this model as presenting a way to purposely integrate the disciplines of STEM within the context of real-world challenges and problems. Johnson argued that:

> an integrated STEM education as an instructional approach integrates the teaching of science and mathematics disciplines through the infusion of practices of scientific inquiry, technological and engineering design, mathematical analysis, and 21st century interdisciplinary themes and skills. (2013: p.367)

Johnson (2013) believed that the integrated STEM model, unlike the STEM enhanced model, offered direct alignment to and with the core curriculum and would accommodate other disciplines such as languages, art and music. Johnson (2013) further argued that some schools in the USA were already using an integrated model for STEM education. Johnson (2013) believed that this approach better represented what was happening in STEM workplaces and research centres. Johnson (2013) suggested that it would be necessary to build teachers' understanding of what was required to implement an integrated STEM model and their capacities to deliver integrated STEM education before any program was implemented. Johnson (2013) also suggested that changes to teacher education courses would also be required.

The provision of different approaches to the implementation of STEM education as suggested by Breiner et al. (2012) and Johnson (2012a, 2012b, 2013) supported a focus on making STEM education meaningful to and beneficial for all students. Zeilder (2016) suggested a way of framing STEM learning and STEM education using a sociocultural socioscientific response (SSR). Zeidler believed that SSR would provide experiences that engaged and challenged students to investigate both local and global issues. SSR sought to connect students' views in their local context with more global ideas. Some of the

components included in SSR were the ethical collection and use of evidence to make decisions and the use of authentic contexts or problems to be solved. Zeidler (2016) further argued that SSR would provide opportunities for students to develop and enhance their knowledge and skills. It could be argued that this would also assist students to better understand the contexts in which decisions were made and to think reflectively about how they could contribute to the resolution of issues that concern them.

Zeidler (2016) sought to frame research related to STEM education within a context of addressing the concerns of the twenty-first century global society. It could be argued that the SSR approach to curriculum development was similar to that of the Neo-progressivism phase. Zeidler (2016) further suggested that using the SSR approach would also build upon gains made by the inclusion of scientific literacy and the nature of science in the curriculum (Lederman and Zeidler 1987) and address the political context that is associated with the introduction of STEM education.

The use of sociocultural socioscientific issues as part of the SSR also allowed students to enhance their use of evidence-based reasoning, argumentation and discussion, by also drawing on knowledge, skills and practices from other disciplines, for example, from the Arts. This hinted at the possibility of STEAM education programs. Zeidler (2016) suggested that it was the nature of the global or local issue that students were investigating that determined how students shaped their solution. This approach integrated the four STEM disciplines in a way that recognised the shared knowledge, skills and practices whilst maintaining their individual integrity and status.

The implementation of the SSR approach to STEM education in the Australian context within the Standards-based reform phase of the curriculum development would require examples of suitable contexts, the required knowledge and skills, the most relevant pedagogy and the most suitable assessment practices. Fensham (2016), cautioned that although the SSR approach showed promise, further research was required as to its applicability to science and STEM education in the Australian context.

The inclusion of engineering in STEM education provided a challenge for those designing curriculum for secondary school students. Engineering had not been previously included as a separate discipline in most secondary school curriculum. Some education jurisdictions in the USA had included technical education in secondary schools which usually led students to specific professions such as automotive mechanics. One approach to the

inclusion of engineering and engineering technology as part of STEM education for secondary school students was proposed by Brower, Grimsley and Newberry (2007). Brower et al. (2007) brought an engineering, technology and mathematic perspective to the inclusion of engineering. Brower et al. (2007) argued for the use of activities-based, project-based and problem-based learning (APPB-learning) that would weave engineering throughout the secondary curriculum and better engage students in STEM education.

Brower et al. (2007) believed that maintaining the STEM disciplines as separate entities would continue the focus on teaching and assessing content rather than shifting the focus to purposely planning for student learning and skills development required for STEM related courses and careers. Brower et al. (2007) further argued that a collaborative or partnership model was necessary if STEM education was to be effective for all students. Brower et al. (2007) also argued that the curriculum for STEM education would be relevant and rigorous if it provided opportunities to build understanding and apply knowledge to practical and real-life problems. Brower et al. (2007) also believed that such a curriculum would need to be flexible to cater for all students and to accommodate meaningful learning relevant to local contexts. This approach by Brower et al. (2007) of weaving engineering into the other STEM disciplines was like the approach to implementing STEM education in the Australian context taken by the Australian Curriculum.

Having seen the introduction and implementation of STEM education in the USA from a federal government perspective, President Barack Obama in his first term of office was keen to set the context for its further development. At the White House Science Fair of STEM education in the USA the president stated:

> One of the things that I've been focused on as President is how we create an all-hands-on deck approach to science, technology, engineering and math. We need to make this a priority to train an army of new teachers in these subject areas, and to make sure that all of us as a country are lifting up these subjects for the respect they deserve. (2013)

In this address, President Obama reinforced his commitment to teacher education as being integral to STEM education and the continuing importance of STEM as an economic and social imperative for the USA.

In response to this address the Committee on STEM education National Science and Technology Council (CoSTEM 2013) released a report that presented a longer-term strategy for the implementation of STEM education and acknowledged the centrality of STEM in

growing the economy and the subsequent increased demand for a workforce with STEM knowledge and skills.

To deliver STEM education, COSTEM identified five priority areas that focussed attention on the type of STEM curriculum, assessment practices and pedagogy required to build capacity, sustain interest and provide equity of access to education and opportunities in STEM education for all students. Programs were directly linked to the purposes of implementing STEM education. COSTEM also addressed how best to use the expertise and resources available within governments, business, academia and communities including professional associations and philanthropic organisations to implement STEM education. First was the need to build new models to facilitate and sustain leadership and collaboration among stakeholders. Second was to construct and apply evidence-based approaches to evaluate the effectiveness of programs and to share best practices across jurisdictions. COSTEM also established a roadmap to implement the strategy which included goals for the short, medium and longer-term and the provision of sufficient resources.

A challenge for science education in the USA was how it addressed the CoSTEM priority that related to curriculum, assessment and pedagogy required to provide support STEM education. In response, a collaboration between twenty-six states, the National Research Council (NRC), The National Science Teachers Association (NSTA) and the American Association for the Advancement of Science (AAAS) led the development of the Next Generation of Science Standards (NGSS 2013):

> To be competitive in the 21st century, American students must have the knowledge and skills to succeed in college and in the knowledge-based economy. Today, students are no longer just competing with their peers from other states but with students from across the globe. (2013)

The basis of this work was the *K12 Framework for Science Education Practices, Crosscutting Concepts and Core Ideas* (NAE & NCR 2014) which was developed to improve the global competitiveness and position of the USA through the provision of a workforce skilled in science, engineering and technology. The NGSS (2013) focussed on connections between concepts to build deep understanding of the fundamental ideas in science and engineering. This approach was designed to provide students with the foundation knowledge skills and practices to progress to becoming scientists, engineers, specialists in technology and technicians if they chose to do so.

The NGSS (2013) were presented learning as a triple helix with three interconnected dimensions, similar to the Australian Curriculum Science learning area. The three dimensions were:

1. *Practices*: how scientists work using knowledge and skills to build models and theories and how engineers work to design and build systems, similar to the Science as Human Endeavour and Science Inquiry Skills strands of the Australian Curriculum.
2. *Crosscutting Concepts*: concepts that are shared across the fields of science, similar to the key ideas of the science learning area of the Australian Curriculum.
3. *Disciplinary Core Ideas*: fundamental knowledge that can be taught, learned and accessed and are directly connected to the students' interests and experiences, similar to the Science Understanding strand of the Australian Curriculum.

This approach to science curriculum provided the opportunity for the NGSS to include education in engineering as engineering practices in response to the CoSTEM priority. This differed from the Australian Curriculum where engineering was addressed in the learning areas of Technologies and Mathematics as well as Science and the General capabilities.

With the continuing impetus to include STEM education in school programs some key stakeholders were concerned with how this was progressing and if there were some issues that should be addressed. One such influential stakeholder, the National Academies of Sciences (NAS), Engineering and Medicine commissioned a report into STEM integration in school education programs in 2014 where the report:

> examined current efforts to connect the STEM disciplines in K-12 education and identified and characterized existing approaches to integrated STEM education, both in formal and after- and out-of-school settings. (2014)

The findings from the report showed that there were multiple approaches to integrating STEM education and a diversity in the level of connections between the STEM disciplines. Using a descriptive framework, the report identified three key implications for the design of future integrated STEM education programs. These were that the integration should be purposeful, explicit, well planned and be able to support students to build their knowledge and understanding in the disciplines and to naturally connect ideas across the disciplines. The report cautioned that integration was not always applicable, for example, when focussing on building understanding of specific, core discipline concepts.

The report made ten recommendations related to research on integrated STEM education in USA. These recommendations were intended for specific audiences including specialists in the design of curriculum and learning activities or experiences and specialists in the design of assessment practices and tasks.

The recommendations emphasised the importance of documenting all aspects of the integration program including setting explicit goals, expected outcomes and the support provided to students, the provision of professional development for teachers in the pedagogy of integration and subject knowledge in the disciplines, creative and innovative assessment practices, suggestions for longitudinal research to study if the articulated outcomes supported learning, thinking, interest, identity and persistence, and the provision of sufficient funding to support all those responsible for designing and implementing integrated STEM education to ensure continuous and meaningful improvement. These recommendations were similar to the requirements for an integrated model for STEM education as presented by Johnson (2013).

In summary, the introduction and implementation of STEM education in the USA provided examples of models, approaches and ideas within a context of growing economic and social prosperity for all its citizens.

## 2.6. The introduction and implementation of STEM education in the United Kingdom (UK)

### 2.6.1 The introduction of STEM education

In 2002, the UK Government was concerned with productivity, innovation and economic competitiveness of UK businesses and industries in the twenty-first century. At the behest of the Government, Sir Garth Roberts, an engineer, reviewed the science and engineering skills available in the current workforce and investigated what skills might be required for the future workforce. Roberts (HM 2002) identified a shortage in numbers of young people pursuing science, technology, engineering and mathematics subjects and related careers. Robert's report (HM 2002) led to the introduction of the acronym SET (Science, Engineering and Technology). There were some parallels with the use of the STS (Science, Technology and Society) acronym in Australia, although Australia included society over engineering, with the design phase of engineering included within technology. Notably mathematics was not included in either acronym.

A collaboration between three government departments, the Department for Trade and Industry, the Department of Education and Skills and HM Treasury led to the introduction of the acronym STEM as part of a science and innovation investment framework (HM 2004). However, Wong, Dillon and King (2016) suggested that references to STEM as SMET were first in publications in the UK as early as 1994.

One of the reasons given for the introduction of STEM education in the UK was to address the declining interest and enrolments in science subjects in the senior secondary years and in courses at the university and higher education levels. This decline was not a new issue or unique to STEM education. Charles Babbage (1830) lamented the decline of science in England and suggested that the then traditional classical education was not providing useful knowledge for the world and opined (1830):

> It is therefore not unreasonable to suppose that some portion of the neglect of science in England may be attributed to the system of education we pursue. (1830: p.25)

### 2.6.2 Implementation of STEM education in the UK

Wong et al. (2016), like Breiner et al. (2012), undertook research into the perceptions or conceptualisations that stakeholders involved in STEM education held and whether these were dependent on their context, for example, if they were an engineer or a mathematics educator or a curriculum officer or a scientist or a politician.

Wong et al. (2016), using the data collected in their study, identified five recurring themes that they believed impacted on how STEM education was understood or perceived. The first of these was that STEM education was seen primarily as a science agenda where science subjects were more important and more valuable than other subjects. Second was the varying perceptions of STEM education where mathematics appeared to be a subset of science and where science was the dominant force with less attention being paid to technology and engineering. Wong et al. (2016) suggested that this would prevent the implementation of an integrated approach to teaching and learning across the STEM disciplines. Third was the lack of published targets for attracting students from previously under-represented groups in senior secondary STEM subjects and a concern that this could lead to an attitude amongst teachers that they need not bother to implement STEM education programs if there was no accountability. Fourth was that as highly able students could now study three science subjects at O levels, the curriculum developed to cater for these students would become more highly specialised. Wong et al. (2016) suggested this would likely lead

to lessening the appeal of studying any science subject at higher levels for the broader group of students. The levels of engagement and interest of students from diverse backgrounds in STEM subjects would likely decrease. So, the very students that STEM policies target for inclusion are inadvertently being excluded by a change to another education policy. Fifth was a concern as to who had access to government and education bureaucracies, who was influencing government policy and what role professional associations, education experts, business and researchers could or should have in advocating for and influencing policies and the development of future policies.

Wong et al. (2016) also argued that the impact of the introduction of STEM education policy has been significant for schools and for some classrooms where STEM subjects or programs have been given a greater prominence. Wong et al.(2016) suggested that this raised the value and importance of STEM education in the eyes of students and parents and the community which was an outcome the government expected from the implementation of STEM education programs.

Wong et al. (2016), like Breiner et al. (2012), also argued that the goal of achieving economic growth and prosperity through the provision of a sufficiently diverse knowledgeable and skilled workforce was unlikely to succeed unless the existing and different perceptions of what STEM education is were challenged. However, Wong et al. (2016), unlike Breiner et al. (2012), argued that a common understanding of STEM education was possible and was required in policy documents before coherent programs in STEM education could be implemented. Wong et al. (2016), like Breiner et al. (2012) and Johnson (2012a), supported an integrated approach to STEM education.

In 2006, a national STEM program was established in the UK and included a centre for STEM Learning. The centre published a succinct vision statement and articulated a purpose. The centre was established and funded as a partnership between stakeholders to pursue actions designed to address teacher recruitment curriculum advice and continuing professional development including in the areas of career advice. These were considered as key factors that were required to successfully implement STEM education in the UK and to deliver the government's agenda of a suitably qualified STEM workforce that will drive economic growth. The centre published a vision for STEM education where:

> Our vision is to achieve a world-leading education for all young people across the UK. STEM Learning is the largest provider of education and careers support in science, technology, engineering and mathematics (STEM). We work with schools, colleges and

> others working with young people across the UK. Supported by a unique partnership of Government, charitable trusts and employers, we are dedicated to raising young people's engagement and achievement in STEM subjects and careers. (2006)

Wong et al. (2016) suggested that although organisations like the UK STEM Centre had a published vision, there was still a lack of a clear understanding among stakeholders as to what STEM education is and expected to deliver.

The inclusion of engineering as one of the four disciplines of STEM education presented two challenges for its implementation in the UK. First were the debates related to how engineering or studies in engineering were included in school curriculum. Second was the active involvement of professional associations as key stakeholders in these debates that would enable them to speak directly to school education authorities or commission reports about the issues related to STEM education. This also led to the expectation that such professional associations would become willing participants in partnerships with schools to assist with the implementation of STEM education.

One such professional association in the UK was the Royal Academy of Engineers (RAE). As one of the more vocal stakeholders in STEM education, the RAE commissioned a report that identified that the UK as facing "an engineering skills crisis" (2016: p.4).

The report expressed concerns that there would not be enough newly trained engineers to fill the gaps resulting from the likely retirement of highly skilled professionals over the next decade. The report (2016: p.4) identified four factors that would impact on the future supply of engineers. These included the lack of interest in and understanding of engineering as a career, low student achievement and enrolment in STEM subjects at school, higher and further education, more young people attracted to careers and courses that do not require STEM subjects and the significant under-representation of women and ethnic minorities in engineering courses. The RAE continued to argue that, although the lack of engineers was often cited as a reason for developing STEM education programs, more was needed to address the coming shortage of engineers. The RAE suggested a cohesive and co-ordinated approach to addressing these challenges that would include modifications to curriculum, pedagogy and assessment and the provision of ongoing professional development for educators. In commissioning the report, the RAE showed a willingness as a partner to engage with the community and education in specific ways and so contribute to and influence STEM education. The RAE placed an emphasis on building a shared understanding amongst those

leading and advocating for STEM education as well as those implementing programs, as advocated by Breiner et al. (2012), CoSTEM (2013) and Wong et al. (2016).

The implementation of STEM education in the UK, much like the USA, focussed on STEM education as providing opportunities for all students to build the knowledge and skills required for their future and the importance of a shared understanding between stakeholders when developing and implementing STEM education programs.

### 2.7 An overview of the introduction and implementation of STEM education in other countries

The Australian Council of Learned Academies (ACOLA) commissioned a report that included an audit of twenty-three countries (developed and developing but excluding Australia) that had implemented policies and programs related to STEM education. The report was prepared by Marginson, Tytler, Freeman and Roberts (2013). This report also included a list of recommendations to support the implementation of STEM education in Australia drawn from the findings of the audit. Freeman (2014) also published an overview of the findings from the report.

The audit revealed that similar characteristics in STEM education were shared between the countries and others that were unique to a specific country. The shared characteristics were representative of the political, economic and social drivers of STEM education, for example growing the nation's economy amid the challenges and complexities of globalisation and an uncertain future. This information is shown in Table 2.6.

**Table 2.6 Shared STEM education characteristics between countries**

| **Characteristic** | **Countries** |
|---|---|
| Enrolments in STEM subjects and courses | Western Europe, UK, USA, New Zealand, Portugal |
| Underrepresentation of groups in STEM subjects, courses and employment | Western Europe, Russia, USA, UK, New Zealand, South Africa, Portugal |
| Performance on international tests | Western Europe, Taiwan, Japan, Russia, UK, USA, Singapore |
| Quality of teaching | USA, Canada, Taiwan |
| Long-term policy agenda | UK, USA, New Zealand |
| Extensive legislative and policy framework overlaying a largely decentralised system | USA, Canada |

The table illustrated that although countries shared some characteristics, the focus of the STEM education programs was specific to each country's local context. For example, Russia, Western Europe and New Zealand were concerned with the underrepresentation of some community groups in STEM subjects, courses and employment. It was the diversity of the enrolments and participation that was the important local issue that STEM education programs were expected to address. New Zealand, like the USA and UK, was concerned with taking a longer-term approach to the implementation of policy related to STEM education. The provision of enough time to achieve the intended outcomes of carefully crafted policies was seen as necessary to ensure effective implementation of STEM education programs.

The unique characteristics identified in the audit introduced new aspects or alternate approaches to STEM education that were specific to the individual country. This information is presented in Table 2.7.

**Table 2.7 STEM education characteristics specific to a country**

| **Characteristic** | **Country** |
|---|---|
| Family involvement | Singapore |
| Scientific literacy | Taiwan |
| Strengthen research and development and technology | Japan |
| Growing access and quality of education | Brazil |
| Biotechnology driven industrial development | Argentina |
| Scale of programs (from local to national level) | New Zealand |
| Innovation driven with priority on STEM | Israel |
| Shift towards STEM disciplines in universities | South Africa |

This table illustrated that STEM education offered the flexibility and opportunity for individual countries to focus on goals and intended outcomes that were unique to their context and that would set them apart from other countries. For example, Singapore, was focussed on including the family and community in STEM education, an approach like that recommended by the RAE (2016). This led to the establishment of *STEMinc.* in Singapore of a centre that offered programs and activities in STEM education for families.

This table also suggested that the nature of STEM education was evolving and would continue to do so as countries strove to grow or maintain economic and social prosperity. For example, as a developing country, Brazil was focussed on providing increased access to quality STEM education programs and to provide enhanced career and employment opportunities for its citizens.

The findings from the audit of Marginson et al. (2013) suggest that when implementing STEM education in Australia as well as drawing from programs and learnings from the USA and the UK, consideration should also be given to investigating if programs from other countries would be suitable for implementation in the Australian context.

UNESCO Education Sector (2017), an international organisation concerned with education, published a report that focussed on the education of girls in STEM. This report addressed the sustainable development goals related to the provision of quality education and gender equality and argued:

> Education systems and schools play a central role in determining girls' interest in STEM subjects and in providing equal opportunities to access and benefit from quality STEM education. (2017: p.11)

This statement identified two factors significant to the implementation of STEM education in developing countries. First was the provision of and accessibility to high-quality programs in STEM education, particularly for girls. Second was the role of particular government's social and economic policies and their application in driving STEM education.

The report (2017: pp.72-73) suggested that there were four levels and seven stakeholders to be considered when implementing STEM education. These were at the individual level with students, at the family level with parents and peers, at the school level with policy makers and teachers and at the societal level with the private sector and media. Three priority actions were also proposed, including ensuring early years care, play and learning opportunities, the provision of good quality, inclusive and gender-responsive STEM education and addressing the social and cultural norms and practices impeding STEM participation, learning achievement and progression. The report argued that such actions would better engage girls in and provide them with greater access to STEM education programs. The report recommended that all stakeholders should be involved in implementation and evaluation of STEM education programs.

The findings from this report were similar to those presented by Australian organisations, including Engineers Australia (2017), The Invergowrie Foundation (Hobbs et al., 2017) and the Australian Government National Indigenous Agency (2019) that were concerned with the underrepresentation of girls, indigenous students and students from low socio-economic communities in higher education and training, careers and employment in STEM and STEM related areas.

Countries were implementing STEM education programs in ways to progress an agenda that reflected a country's priorities for its economic future, the social prosperity of its citizens and its international standing and influence. Within these programs there were shared goals or intended outcomes including:

- increased access, participation and retention from previously underrepresented groups in STEM and STEM related courses and employment;
- improved rates of literacy and numeracy;
- improved student performance on international testing programs;
- government legislation and investment that supports innovation, growth and social cohesion;
- improved economic performance locally and globally;
- development of knowledge and skills that can take advantage of advancing technology;
- planning for a challenging and complex future.

## 2.8 The introduction and implementation of STEM education in Australia

### 2.8.1 The introduction of STEM education

Since 1901, successive Commonwealth Governments, using money collected from taxes, have provided grants to the states and territories to assist them to fund programs in education. The Council of Australian Governments (COAG) was established as a forum where the Ministers for Education from the Commonwealth and the states and territories collaborate to ensure access and equity of access to high-quality education for all Australians irrespective of where they live.

In 2001 and at a similar time to the introduction of STEM and STEM education in the USA and UK a significant piece of research was undertaken by Hackling, Goodrum and Rennie for the Commonwealth Government Department of Education Teaching and Youth

affairs (DETYA, 2001). Their research described ideal practice in the teaching and learning of school science, the actual nature of teaching and learning of science in Australian schools and made recommendations to move the situation in Australian towards their ideal practice in science. Hackling et al. (DETYA, 2001) argued that the inclusion of scientific literacy in Australian science curricula was essential to ensure quality outcomes in science education for all students. They explained that scientific literate people would be:

> interested in and understand the world around them, engage in the discourses of and about science, are sceptical and questioning of claims made by others about scientific matters, are able to identify questions, investigate, and draw evidence-based conclusions, and make informed decisions about the environment and their own health and well- being. (2001: p.3)

Hackling et al. (DETYA, 2001) also found that there was a difference between the enacted curriculum and the published curriculum, that the enrolments in senior secondary science and mathematics subjects were declining, that teaching as a profession was undervalued by the community and that teachers were feeling that their work included more and more non-teaching duties. These findings were reflected in the reasons provided for the introduction and implementation of STEM education as discussed by Breiner et al. (2012) Tytler (2007) and Wong et al. (2016).

The recommendations Hackling et al (DETYA 2001) developed to improve the status and quality of science education were underpinned by five fundamental premises: the purpose of science education was to develop scientific literacy, the focus for change was narrowing gap between the actual and ideal situation for teaching and learning in science, teachers were the key to change, change takes time and resources, and collaboration was essential for quality science education. These recommendations were also similar to those from more recent research publications related to STEM education by Marginson et al. (2013), Chubb (2013a), Finkel (2016a) and ECA (2018).

The acronym STEM and the term STEM education were first introduced in Australia in 2013 at the National Press Club, Canberra by the then Chief Scientist for Australia, Dr. Ian Chubb. He (2013a) argued that there was a need to introduce STEM as a matter of urgency if Australia was not to be left behind other nations. Chubb referred to what was happening in the USA, China and other Asian economies and the importance of a high performing education systems. Chubb (2013a, 2013b) presented STEM education as being of benefit to all Australians and stressed the importance of innovation for growing Australia's economic

and social prosperity. Chubb also encouraged all stakeholders to embrace STEM education through collaboration and partnerships with a focus on building competitiveness and supporting high-quality education and training and emphasised:

> We are the only OECD country without a science or technology strategy. Other countries have realised that such an approach is essential to remaining competitive in a world reliant on science and science-trained people. (2013a: p.10)

It could be argued that Australia benefited from the later introduction and implementation of STEM education as it did not have to endure arguments about the form of the acronym and had recently developed the Australian Curriculum that included learning areas, general capabilities and achievement standards. Australia was also facing similar issues to USA and UK, for example, declining enrolments in science and mathematics subjects and courses, a shortage of qualified teachers in the STEM disciplines, lower performance by students on international tests when compared to neighbouring Asian countries and the underrepresentation of groups, for example indigenous students and girls in STEM and STEM related courses, careers and employment.

### 2.8.2 Implementation of STEM education in Australia

The implementation of STEM education in Australia, like other countries, has caused debates as to the content of programs and approaches used to deliver these.

Blackley and Howell (2015), from Curtin University, Western Australia, drew attention to the implementation of STEM education in Australia by revisiting the rise of STEM at an international level and suggesting a way forward for future STEM education initiatives. Blackley and Howell (2015) proposed that there were two perspectives to the development of the STEM narrative, the political and the educational, each with a separate and different agenda that shaped the nature of the expected outcomes. These two perspectives were consistent with the work of Breiner et al. (2012) and related to the conceptualisation of STEM education. Although, Blackley and Howell (2015) did not specifically address how an individual conceptualises STEM education (the third perspective from Breiner et al., 2012), it was inherent in their references to prosperity and community participation.

Blackley and Howell (2015) also identified four distinctly different geo-social approaches to the introduction of STEM and STEM education. First, Blackley and Howell (2015) argued that the focus in the USA and the UK was on a *STEM crisis,* where the dominant discussion emphasised the need for changes in curriculum, pedagogy, teacher skill

levels, student motivation and subject selection to ensure future economic prosperity. Linking education to economic prosperity to avoid a crisis was an example of how the political narrative shaped the STEM agenda and was suggestive of a deficit model approach to the implementation of STEM education.

Second, Blackley and Howell (2015) suggested that the focus in France and Germany was on a *STEM shortage* where national industry and education policy emphasised a positive approach to improving the community's understanding of and increased participation in STEM based subjects and careers. This developing of policy that linked industry and education and included the community was illustrative of the use of an educational narrative to shape the implementation of STEM education.

Third, Blackley and Howell (2015) believed that Korea, Japan, China and Taiwan had well-established national policies related to science, technology, research and development driven by industry and universities. This enabled these countries to undertake significant reforms in STEM education to ensure continued high-quality student achievement and outcomes. The emphasis on research and development to deliver reforms demonstrated how the education narrative was driving the implementation of STEM education.

Fourth, Blackley and Howell (2015) explored the focus of two developing countries, Brazil and South Africa. Similar to Marginson et al. (2013), Blackley and Howell (2015) found that these countries were focussed on improving participation in education and the training and the provision of a more qualified cohort of teachers. This approach linked prosperity to a better educated and trained population and a more highly qualified teacher workforce, illustrating how aspects from both the political and educational narratives had shaped the implementation STEM education.

Blackley and Howell (2015) further suggested that careful consideration should be given to the success or otherwise of current STEM education programs to determine how teachers and curriculum developers understood what STEM education offers and is expected to achieve. It could be argued that such a discussion was also required as to whether STEM education programs would be better targeted at lower secondary and upper primary levels or included from early childhood or as an option for senior secondary specialist courses.

In response to the issues raised by Chubb (2013a), both the Australian Government and some state and territory governments developed and released policies related to the implementation of STEM education. These included:

- *The National STEM School Education Strategy. A comprehensive plan for Science, Technology, Engineering and Mathematics Education in Australia 2016-2026* (ECA, 2015). (A collaboration between of the Commonwealth and state and territory Ministers of education.);
- *Roadmap to STEM education in Queensland* (2013) and *A strategy for STEM in Queensland state schools* (2016);
- *Learning for the Future and leading STEM* (New South Wales, 2017);
- *VicSTEM Science, Technology, Engineering and Mathematics. STEM in the Education State* (Victoria, 2016).

These publications sought to provide directions as to how to increase student interest and engagement in STEM education programs and careers and to increase the access of all students to a curriculum that challenges them to design and engineer creative solutions to real-world problems through working in collaborative teams. This approach supports a pedagogy that uses guided student inquiry to develop knowledge, skills and understanding in STEM education from the early childhood through to tertiary education and training. These publications also supported a collaboration between all those with an interest in the implementation of STEM education to deliver increased student achievement and outcomes.

Australia, like other countries, has grappled with issues related to the inclusion of engineering in school education programs. Lyn English, from the Queensland University of Technology, is an internationally recognised researcher whose areas of research includes the place of engineering education in STEM education. English acknowledged the important role STEM education has in building economic growth (2017: p.6) and suggested that its implementation required further research. English (2017: p.5) argued that among stakeholders there were varying opinions that depended on context, for example, the school or curriculum or the political environment as to how to proceed when implementing STEM education. In a review of academic literature and media publications, English (2017), identified five core issues that she argued impacted on decisions related to curriculum, pedagogy and assessment that directly affected what happens to STEM education in classrooms. These were perspectives on what STEM education is and could achieve, approaches to implementing STEM education, representing the STEM disciplines, equity in access to STEM education for all students and extending STEM to STEAM to incorporate the Arts. English (2017), like Johnson (2012a), argued that STEM education was for all students and that high-quality professional development to support teachers design and

implement programs was required. Both English (2017) and Johnson (2012a, 2012b) also emphasised that a better understanding of STEM education and what it offers was required to progress its successful implementation.

Debates about what STEM education means often centre around what actually is and is not STEM, the role of each of the four STEM disciplines and what the integration of the disciplines would look like. English (2017), like Johnson (2012a, 2012b), supported STEM integration as a way of showing the naturally occurring links between the disciplines, providing the contexts for investigating real-world problems and assembling teams that harness the diversity of expertise, experiences and skills of all team members to find solutions to these problems.

Hudson, English, Dawes, King and Baker (2015) undertook research that investigated how teachers could be supported to design and implement STEM education programs in Australia. Hudson et al. (2015) identified the importance of the inclusion of content and activities that were age appropriate and relevant to the interests of the students, pedagogies that supported engagement and inquiry and assessment tasks that focussed on the application of knowledge and skills to solve problems in STEM education programs. Hudson et al. (2015) also developed an eleven-point criteria framework of content, assessment and pedagogy to assist teachers working in teams to design and evaluate STEM education programs.

In Australia arguments have been made to include the Arts in STEM education programs to embed creativity to become STEAM education. Peter Taylor from Murdoch University, Western Australia, is a strong advocate of STEAM. Taylor argued (2016) that the inclusion of the Arts into STEM was essential to prepare young people to meet and resolve the challenges that the future would likely present to them. The use of the term STEAM remains contentious in Australia suggesting that further investigation of the benefits and viability of STEAM education programs is required.

The role of partnerships in implementing STEM education has also been of interest to Australian researchers including Kerry Bissaker, Flinders University, South Australia. Bissaker (2013) conducted research at the Australian Science and Mathematics School into the role of partnerships in the implementation of STEM education. Bissaker argued (2013) that to contend with the complex problems of the future, students would also need to develop a world view of issues. Bissaker (2013) also explained that students should be encouraged to

investigate the likely impact of the possible solutions they developed for problems or issues at the local and global level.

Bissaker (2013), like Marginson et al. (2013) and Finkel (ECA, 2018), suggested that this approach would require professional development for teachers that focussed on developing specific knowledge in the STEM disciplines that included the latest developments in the disciplines. Bissaker (2013) also argued that the design and implementation of innovative curriculum and pedagogical and assessment practices in STEM education come from professional partnerships between teachers and academics from the STEM disciplines and education, as also suggested by Schwab (1983). Bissaker (2013), like Chubb (2013), Hudson et al. (2015) and English (2017), argued that building respectful relationships and understanding between partners was essential to sustain productive partnerships where each partner brings a valid and valuable set of experiences and expectations that will contribute to successful outcomes.

Promoting an integrated approach to STEM education in Australia and elsewhere is not without its challenges. In a keynote address in 2014 to the international conference in Canada, *STEM education and Our Planet: Making Connections Across Contexts,* David Clarke, Director of the International Centre for Classroom Research (ICCR), encouraged participants to think differently about STEM education. In this address, Clarke (2014) argued that to unite the four separate STEM disciplines which otherwise seem to have little in common would require a fresh approach. Clarke (2014) proposed that this approach would draw on the natural strengths of each discipline and look for natural connections or relationships that exist between the disciplines. This approach shared some similarities with that suggested by Johnson (2012a) and English (2017). Clarke (2014) further explained that, rather than being in competition, the four disciplines should look for real opportunities to share, discuss, evaluate and collaborate in partnership to progress the implementation of STEM education.

Dr. Alan Finkel, as Chief Scientist of Australia (successor to Dr. Ian Chubb) continued his predecessor's advocacy of STEM education and focussed on what the workforce for tomorrow would look like. Finkel (2016a,b) argued that the acquisition of STEM skills was critical to Australia's future prosperity and required a multifaceted approach to developing STEM education programs. This led to the release of the STEM Program Index (SPI) (Finkel 2016b), a publication that listed the many organisations across Australia which wanted to help schools and parents with STEM education programs. The program were aligned to the

Australian Curriculum learning areas of Science, Digital Technologies and Design and Technologies, and Mathematics. Finkel believed, like the RAE (2016), that it was important to inform all members of the community about STEM education to gain interest and support for productive partnerships between stakeholders.

Finkel continued to focus attention on the crucial role of partnerships in supporting the implementation of STEM education in Australia. Finkel (2018) canvassed the opinions and ideas from parents, teachers, school leaders, industry and business, governments and university and higher education providers as to what was required to provide all Australian students with the best possible STEM education. The detailed report Finkel prepared for Education Council Australia (2018) was positive but also sounded a note of caution:

> Science and mathematics education in Australia is far from broken but it is clearly not where it should be. (2018: p.6)

Finkel (ECA, 2018) argued that partnerships between the key stakeholders were essential if STEM education was to be successfully implemented in Australia. Finkel (2018) also acknowledged that each stakeholder brought specific areas of expertise to discussions about STEM education and that this should be recognised and valued. The report included recommendations in areas related to the knowledge and skills all young Australians will require for future careers and employment, improving the achievement outcomes for all students, ongoing professional development programs for school leaders and teachers to develop and implement high-quality of STEM education programs and collaboration between partners to develop resources for students, teachers and the community.

Although these recommendations were consistent with those made by international researchers, there were two recommendations that were specific to Australia. First was a review of the ATAR, the selection tool based on results from the completion of Year 12, the final year of secondary education in Australia. The ATAR is used to select students to higher education courses. Second was the alignment of STEM education and programs with the National STEM School education Strategy (ECA, 2015). Discussion of these two recommendations is ongoing.

Marginson et al. (2013: pp.15-16) further suggested that it was necessary to deepen and broaden STEM education programs in Australia. Marginson et al. (2013) argued, that this was necessary if concerns about improving student performance on international testing programs, increasing the participation and retention of senior secondary students in

mathematics and the sciences and addressing gender disparity in enrolments in tertiary STEM courses were to be addressed. Marginson et al. suggested that there were five features that countries they regarded as strong in STEM education (for example, Finland, China, Russia and South Korea) shared and that were relevant to Australia.

First was the higher level of teacher qualifications in at least one discipline of STEM and education, salaries and career structure. In Australia, the salary and career structure is generally based on years of service and is independent of teaching subjects or level of higher education qualifications.

Second was a consistent focus on the content of the disciplines for teachers and students. Currently in Australia teachers often teach *out of field* in areas where they have not been trained and professional learning offered is often more generic than discipline specific.

Third was engagement of students through an inquiry approach that promotes critical and creative thinking. In Australia many schools and teachers already use this approach.

Fourth was proactively working to include students who in the past had been excluded. For example, Australia has been working to improve the education outcomes for indigenous students through initiatives like Closing the Gap. (2019). There have been some successes but all governments have acknowledged that more work is required achieve better outcomes.

Fifth were National STEM policy frameworks that included centrally and funded programs. Whilst there are existing national STEM education policies in Australia, there are also state government policies unique to their local contexts that education settings in these jurisdictions are expected to implement. The implementation of STEM education across Australia is unlikely to be uniform.

Although Australia was making good progress in some areas Marginson et al. (2013: p.12), believed that were opportunities for further improvement particularly in the levels of student achievement in literacy, numeracy, science and mathematics and reducing the gender disparity in STEM subjects, courses and employment. However, Marginson et al. (2013: p.19) cautioned against transferring international policies and educational practices directly into the Australian context.

Marginson et al. (2013: pp.20-28), also identified specific areas that they believed should be discussed at the national level and used to inform future STEM education policies and programs in Australia. From a curriculum perspective, Marginson et al. believed that there should be a higher focus on student engagement and achievement, that studies in

mathematics and sciences should be made compulsory to Year 12, that specific prerequisites should be introduced for higher education courses and that an increased focus be placed on the diverse nature of careers available for people with engineering or technology degrees. When focussing on pedagogy, Marginson et al. suggested the inclusion of thinking skills, creativity and design activities and standardised testing assessment in education programs. Marginson et al. (2013: pp.20-28) argued that to address the disparity in student access to and participation in STEM education programs mentoring programs and curricula and pedagogy that were culturally responsive to the students should be introduced. Marginson et al. also believed that to ensure teachers were prepared to implement STEM education there should be a focus on the level of qualifications required with remuneration for higher levels of expertise, discipline specific professional development for secondary teachers and the specific teaching of science and mathematics at all levels in primary schools. Marginson et al. recognised that an informed community that understood the career and employment opportunities provided by STEM education was also necessary. Similarly bringing all stakeholders together to collaborate and share programs, ideas and opinions would build partnerships leading to enriched STEM education programs.

### 2.8.3 Towards a vision for STEM education in the Australian context

The work of Marginson et al. (2013) and Tytler (2007) suggested that a vision for STEM education in the Australian context was required. To assist with the development of such a vision, a review of visions for STEM education published by governments, professional associations and organisations was undertaken. The visions selected were drawn from government and semi governments representative of the countries included in the report prepared for ACOLA (Marginson et al., 2013) and referenced in Australian publications related to STEM education. The five vision statements selected were from the USA, the UK, the Republic of Ireland, the European Union and Singapore. Australia in the past has drawn from the curriculum of the USA and the UK, hence the selection of vision statements from these countries. The selection of a vision statement from Singapore was included to provide a perspective from an Asian country and one with which Australia has close regional ties (for example, in education, trade and security). The selection of vision statements from the Republic of Ireland and the European Union was to provide a perspective from Europe and move beyond the more traditional sources of the USA and the UK.

*STEMinc*. (2014) and the European Union STEM Coalition (2016) framed their respective visions for STEM education as mission statements that were underpinned by a set of objectives. The USA Department of Education (2016), the National STEM Learning Centre (UK 2016) and the Republic of Ireland (2017) provided vision statements for STEM education accompanied by an explanation of what was required to achieve this vision. The Republic of Ireland (2017) also situated STEM education within the wider context of education and training. The vision and mission statements reinforced the relationship between economic and social prosperity and the role of STEM education in developing informed citizens capable of making decisions that will secure their future and their nation's future.

There were shared features and expected outcomes within the different vision statements. The shared features were that STEM education nurtured the next generation of specialists, supplied the skilled workforce for now and the future and included real-world learning experiences in education programs. The shared features of what was required to achieve the visions and mission statements included partnerships between the stakeholders to design and implement programs that increased student engagement and participation in STEM subjects and courses, high-quality teaching and learning supported by ongoing professional development for teachers and improved access for all groups to STEM education, including in higher education and employment.

In addition, *STEMinc.* (2014) included an emphasis on encouraging families to be active participants in STEM education programs The European STEM Coalition (2016) adopted a triple helix approach where academia-industry-government worked together in all aspects of STEM education. The UK National STEM Learning Centre (2016) and the Republic of Ireland (2017) visions expressed the desire for their STEM education programs to be recognised as examples of world's best practice in STEM education.

### 2.9 Developing the Research Question for this study

The literature review of the introduction of STEM education internationally and in Australia identified the key drivers of and the context for its implementation. Governments, business and industry and professional associations argued that STEM education would deliver economic and social prosperity in the twenty-first century provided certain conditions were met. This included a suitably STEM-skilled and knowledgeable workforce that was flexible, creative and resilient, capable of making informed decisions and solving challenging

and complex problems. To do this would require STEM education programs that provided access to all students that better engaged them with learning in the four STEM disciplines. This, in turn, would lead to increased enrolments in STEM related subjects and careers into and beyond the post compulsory years of secondary schooling. Underpinning this was the need for highly qualified and competent teachers, the provision of ongoing professional learning in content and pedagogy, a curriculum that included content and contexts relevant to students and innovative assessment tasks and practices. Accountability as measured by student progress and achievement against set standards and improved rankings on international and national testing programs was also an expected outcome from STEM education programs.

The drivers of and reasons for STEM education were similar across countries (Marginson et al., 2013). However, there was less agreement as to the best approaches to implement STEM education programs. An integration approach to implement STEM education had support from educators like Johnson (2014) and English (2017). Other researchers suggested a socioscientific approach (Zeidler 2016) and the combination of integration and specialist approaches (Marginson et al., 2013). Therefore, my study will investigate whether those interested in STEM education would accept diverse approaches for its implementation in the Australian context.

The findings from the research of Breiner et al. (2012) and Wong et al. (2016) suggested that the successful implementation of STEM education required all stakeholders have a shared conceptualisation or understanding of what it is and how it should be implemented. My study will investigate if a shared conceptualisation of STEM education exists amongst key stakeholders in Australia and if this could be expressed as a vision for STEM education in the Australian context. It will also investigate how a shared conceptualisation of STEM education is achieved, given the diverse nature of those working to implement STEM education programs in any specific context.

The work of the selected international and Australian education researchers was used to investigate how curriculum developed from the 1850s to 2000s. A curriculum development framework based on that DeBoer (2014) suggested for the science curriculum and the work of the education researchers, Huxley, Dewey, Tyler, Schwab, Young, Bybee, Fensham, Boomer and Tytler was used to underpin this study.

Similarly, a vision for STEM education in the Australian context would also be expected to reflect the phases of curriculum development and the features of each phase that are applicable to STEM education. Boomer (1992) reminded educators and policy makers in Australia that the engagement of all students with their learning to assist their acquisition of knowledge and skills to meet future challenges was critical when planning education reforms.

The literature review also identified challenges in the implementation of STEM education that may be relevant to the Australian context. This included, for example, which pedagogies would be more effective, where and how STEM education is best included in the curriculum and what are the appropriate types of assessment tasks and assessment practices.

This study will investigate the introduction and implementation of STEM education in the Australian context, drawing on comparisons with relevant international and national policies, programs and research and the opinions and the experiences of a group of selected Australians interested in STEM education. This study will also seek to identify the challenges facing STEM education in the Australian context.

### 2.9.1 The overarching research question for this study

What are the challenges for STEM education in the Australian context?

To construct a response to this question, a document analysis, a Delphi study and semi-structured interviews were undertaken, and the data collected and analysed. Each of these methods addressed a set of sub questions.

### 2.9.2 Research Questions to be addressed by the document analysis

1. What common themes were evident in the documents selected as being representative of the published authority?
2. How do these themes relate to the phases of curriculum as presented in the curriculum development framework?

### 2.9.3 Research Questions to be addressed by the Delphi study

1. What are the purposes for STEM education and the requirements for its implementation in the Australian context as identified by selected participants?
2. How do the selected participants conceptualise STEM education?
3. Do the selected participants have a preferred vision for STEM education in the Australian context?

### 2.9.4 Research questions to be addressed by the semi-structured interviews

1. What can be learnt from past experiences in education reform that will enhance the implementation of STEM education in the Australian context?
2. What is the likely next step or future opportunities for STEM education in Australia?
3. Which of the three visions developed in the Delphi study was preferred by a small group of participants from the STEM education community? What were the reasons for given their choices?

## 2.10 Conclusion

Although the introduction of STEM education in Australia was later than that in the USA, Europe and parts of Asia, it has gained acceptance and is now included in a variety of publications produced by Australian stakeholders.

The curriculum development framework will underpin this study and guide the collection and analysis of the data to identify the current and possible future challenges for STEM education in the Australian context.

In developing an understanding as to why STEM education is gaining so much attention now in Australia, questions related to the purposes and requirements of STEM education need to be asked. Exploring whether the current political economic and social environment are conducive to longer term planning that will sustain STEM education is also important. This will determine if a vision for STEM education in the Australian context can be constructed that supports the delivery of high-quality programs for all young Australians.

The literature review suggested that there was a diversity of opinions about what STEM education is and what its implementation was expected to achieve. This suggested that multiple methods would be required to investigate the challenges facing STEM education in the Australian context. This led me to select three different methods to collect and analyse data to address the research questions and the use of a narrative inquiry approach to present the findings from this study. The methods selected were a document analysis of selected international and Australian publications, a Delphi study and semi-structured interviews conducted with selected participants from across Australia.

The following chapter will discuss in detail the methods used in this study: narrative inquiry approach, the Delphi study and the semi-structured interviews used in this study.

# Chapter 3: Methodology

This chapter describes the methodology applied in this study. A narrative inquiry approach was used to present the analysis of the data collected from the three different methods used. The first of these methods was a document analysis of international and Australian publications related to the introduction and implementation of STEM education. The second method was a Delphi study and the third method was a series of semi-structured interviews with selected participants. As this study was investigating the challenges for STEM education in the Australian context, all the participants selected to complete the Delphi study and the semi-structured interviews were from Australia. A number of these participants also had international experience in education research. The findings from the analysis of the data collected from each approach were presented as a narrative to better understand the challenges facing STEM education in the Australian context.

## 3.1 Narrative inquiry approach

### 3.1.1 Introduction

Narrative inquiry has a long history of use in research that focussed on understanding people, their cultures and lives through their lived stories including anthropology, psychology and education. Clandinin and Connelly (2000) argued that its use in education research has grown steadily over the past twenty years. The narrative inquiry approach was appropriate for use in this study because it provided a way to capture, respect and present the experiences and the opinions of the selected participants related to the introduction and implementation of STEM education in the Australian context.

Clandinin and Connelly (2000) presented narrative inquiry as being both the *phenomenon* and the *methodology* of research in education because it used the participants' stories to construct meaning and understanding of events. In this study, the phenomenon was STEM education in the Australian context, its introduction and implementation investigated through the analysis of documents, and the opinions of the selected group of participants.

Clandinin and Rosiek (2007*)* argued that although narrative inquiry can be situated alongside other forms of inquiry, for example, post-positivist or post-structuralist, it was a distinctive form of inquiry that studied the lived experience. Clandinin and Rosiek (2007*)* (2007: pp.69-70) used a Deweyan understanding of experiences to explain the particular dimensions that mark the landscape and boundaries of narrative inquiry that had been

previously identified by researchers, including Connelly and Clandinin (2006) and Mishler (1986). These dimensions were *temporality*, *sociality* and *place* which formed a three-dimensional inquiry space (Clandinin and Rosiek 2007*)* that accommodated multiple interactions between the data collected from the three methods used in this study. The dimension of *temporality* described the contexts or conditions in which a specific change in policy or reform to education was initiated from the perspective of those who were impacted by the changes both intentionally and unintentionally. In this study, *temporality* was addressed by investigating how the selected participants understood the introduction of STEM education and its purposes and requirements in the Australian context. The dimension of *sociality* described the people or groups of people that were linked in the narrative constructed through their interest and experiences in an event or series of events and how this may impact or shape future events. In this study, *sociality* was addressed by asking the participants to reflect on their experiences in education reform and to consider what would be required to successfully implement STEM education in the Australian context. The dimension of *place* referred to the position and point of time in which the narrative was constructed. In this study, *place* was addressed by exploring selected international and Australian documents related to the introduction and the implementation of STEM education.

Clandinin and Cain (2012: pp.169-175) introduced twelve *Qualitative Touchstones* to address how the quality of narrative inquiry could be achieved and maintained. These twelve touchstones described the responsibilities of the researcher using a narrative inquiry approach and the trust the participants place in the researcher to accurately recount their stories. In this study the touchstones were addressed as follows:

- *Relational responsibilities*: the researcher behaved ethically in all aspects of the research and with all communications and interactions with the participants, including secured storage of all data collected;
- *In the midst*: the researcher acknowledged their professional and personal experiences that would likely impact on how the research is conducted and the possibility of future work with the participants;
- *Negotiation relationships*: the researcher established and abided by protocols for all interactions with the participants;
- *Narrative beginnings*: the researcher undertook ongoing reflections on the research in discussions with their academic supervisors;

- *Negotiating entry to the field*: the researcher noted and attended to the contexts in which the participants would relate and reflect on their experiences;
- *Moving from field to field texts*: written texts were collected from the document analysis, the Delphi study and the transcripts from the semi-structured interviews and included de-identified quotes;
- *Moving from field texts to interim and final research text*: an iterative process was used where the data and the analysis of the data were revisited as was attending to the personal, practical and social justifications for the research;
- *Representing narratives of experiences in ways that show temporality, sociality and place*: questions asked in the Delphi study and semi-structured interviews engaged the participants in thinking about and reflecting on STEM education from their perspective to provide possibilities rather than definitive answers;
- *Relational response communities*: conference presentations provided opportunities for the educators to provide feedback or offer a critique of the different phases of the research to the researcher;
- *Justification-personal, practical, and social*: the researcher addressed questions related to why this study is needed now, what research questions will be posed, who will participate in the research, how best to practically conduct the research and what information will be presented at conferences in regular discussion with their academic supervisors;
- *Attentive to audience*: the researcher kept detailed notes to illustrate how the multiple contributions to the research from the selected participants and from members of the audience at conference presentations were balanced and managed;
- *Commitment and understanding lives in* motion: the researcher acknowledged that this study was undertaken at a specific time with a group of selected participants and as such would contribute to evolving research related to STEM education.

Webster and Mertova (2007: p.79) argued that when using a narrative inquiry approach to understand how experiences have shaped people's opinions and ideas, attention should be paid to identifying events that were influential or significant to any of the participants involved in the narrative. Webster and Mertova (2007: p.79) defined three types of events they believed contributed to the narrative: "*critical*, *like* and *other"*. First, a *critical event* was defined as being unique, illustrative and confirmatory in nature and likely to have a profound impact and effect on whoever experienced the event and often brought about radical change

in the person. Webster and Mertova (2007: p.83) further explained that critical events were unplanned and unanticipated and have three qualities. The first of these qualities was that these types of events existed within a specific context, for example, as organised structures or communities of practice. The second quality was the impact on the people involved and that this may have life-changing consequences. This was less likely to be relevant in education but particularly relevant in the health sciences. The third quality was that the event may reveal patterns of well-defined stages that were only identified after the event and were intensely personal with strong emotional involvement.

Second, a *like event* occurred in a similar way to that of a critical event and further confirmed, illustrated and repeated the experience of the critical event but with different people and so may have broadened issues that arose from a critical event.

Third, an *other event* was a further event that took place at the same time as the *critical* and *like* events and was presented as anecdote or incidental but was interwoven and visible in the analysis of critical and like events. In this study, the participants' responses to the questions asked in the Delphi study and recorded in the semi-structured interviews were analysed to identify examples of each type of the three events.

Daiute (2014), like Webster and Mertova (2017), pointed to the tensions that existed between the principles and goals of a narrative inquiry and how these impacted on the quality of research that used a narrative inquiry approach. These tensions arose between generalisations and data that were expressed through the voices of the participants using direct quotes. Daiute (2014) argued that there were three causes of these tensions. The first cause was the role of the researcher as both conducting and participating in the research (principle) and the role of the participants as having experiences and reflections (principle) relevant to forming responses to the research questions (goal). The second cause was the personal (principle) and the political nature of the narrative and the audience response (goal). The third was defining the narrative and its parameters including the selection of participants, processes for collecting the reflections and experiences of the participants (principle) to ensure the research contributes new knowledge or understanding (goal). Daiute (2014: pp.25-27) further argued that these tensions should be addressed and presented as checklists to assist with the preparation and analyses of narrative inquires that focussed on the identification of significant events, similarities and differences in how the participants reflected on their experiences and how this is related to the research.

In this study, to address these possible tensions, five items from the checklists Daiute (2014) provided were included in the document analysis. These were the identification of context or setting, the authorship, the key points, the outcomes and the intended audience. Items from these checklists were also used in the analysis of the Delphi study and the transcripts from the semi-structured interviews. These were the grouping of similar responses, the identification of differences in responses and any unique responses and recording any additional comments provided by the participants. The possibility of the impact of these tensions on the quality of the narrative inquiry approach used in this study was also addressed in the declaration of the researcher's stance discussed in 3.1.4.

A narrative inquiry approach supports exploring the learning people have had that leads people to a particular position on an issue. Bruner (1986) observed that learning occurred as a sharing and communal activity making it is possible to explore how people learn and understand the world around them. It could be argued that the critical events as defined by Webster and Mertova (2007) or the significant events proposed by Daiute (2014) were examples of Bruner's learning within the community (1986).

Bruner (2002: p.2) revisited the use of stories as a way of sharing learning and proposed that stories satisfied people's need to understand and explain what they were doing. Bruner also emphasised the need to acknowledge the narrative as being told from the author's perspective and their interpretation of events and to trust that the author would make their position clear in the telling of the story. In this study, the declaration of the researcher's stance provided the reader with the context for the narrative (Bruner, 2002: p.2) presented in this study. It was also important that the researcher reflected on their stance as the study proceeded and again when it concluded, as discussed in 7.10.

Pinnegar and Daynes (2007) argued that narrative inquiry produced an interactive quality to the relationship between the data collected and the analysis of the data that leads to an enhanced quality of the narrative constructed. Pinnegar and Daynes (2007) further suggested that the four assumptions that underlie the paradigmatic knowing as identified by Bruner (1986) should be used when assessing the quality of the narrative. First was the use of the narrative inquiry to provide a coherent and connected story that was explained, discussed, questioned and described. Pinnegar and Daynes (2007) also explained that this could be equated to the use of reliability in other types of research. Second was the use of the narrative to show the relationship between people and their interactions involved capturing the essence of the person, the time and the context. Pinnegar and Daynes (2007) further argued that this

could be equated to the use of objectivity in other types of research. Third was the use of the narrative to understand the complexity of the interaction between the individual, the context and the issue under investigation. Pinnegar and Daynes (2007) also suggested, that unlike other types of research, generalisation was not a required outcome of narrative inquiry, rather narrative inquiry presented the responses to the issue from a selected group of participants at a specific point in time. Fourth was the use of the narrative to build understanding of the specific issue but not to seek to control or predict the outcomes unlike other types of research. Pinnegar and Daynes (2007) argued that the term validity as traditionally used to assess the soundness of research was not applicable to narrative inquiry and proposed that it was the credibility of the research from which the narrative is constructed that was important.

### 3.1.2 Mitigating the risks of narrative inquiry in this study

In this study, the risks (Clandinin and Caine (2013) and Pinnegar and Daynes (2007)) associated with the use of a narrative inquiry approach were addressed by the development of strategies. These included maintaining the anonymity of the participants, establishing the credibility of the research, maintaining the trust required in relationship between the prominent community members and the researcher, how the researcher's experiences influenced or shaped the research and ownership of the stories and the way in which these were told. These were addressed as follows:

*Anonymity of participants*: the Plain Language Statement (PLS) and the Consent to participate stated that anonymity of all participants would be maintained. A letter of the alphabet was ascribed to each participant to de-identify the data or quotes they provided in the Delphi study and the semi-structured interviews. All participants were treated equally and the organisations they represented also remained anonymous.

*Credibility of the research*: the criteria for selection of the documents analysed and for the selection of the participants in the Delphi study and the semi-structured interviews were stated to provide transparency and to show the status of the selected documents and participants. This was done to provide the reader with a credible picture of the source of the data used to construct the narrative. The findings from this study were presented as the responses to the introduction and implementation of STEM education in the Australian context. The findings were not presented as a definitive response from all people with an interest in STEM education. The identification and mitigation of any factors that would affect

the collection and the analysis of the data and the published findings were intended to prevent the research from becoming just a good story.

*Maintaining the trust required in relationships between the participants and the researcher:* the PLS and Consent to participate clearly stated that all data would be de-identified and that each participant would be provided with a transcript of their semi structured interview to review and amend as required. Permission from the respective participants was also sought before any quotes identified in the transcripts were published.

*How the researcher's experiences influence or shape the research:* this was acknowledged in the declaration of the researcher's stance and in the selection criteria developed and applied. The analysis of the data collected in this study was also underpinned by the researcher's experiences, particularly in curriculum design and implementation.

*How the researcher's experiences influence or shape the research:* this was acknowledged in the declaration and reflection of the researcher's stance in 3.14 and 7.10 respectively.

*Ownership of the stories and the way in which these are told:* the data belonged to the participants and were shared with the researcher. The data was de-identified prior to its inclusion in the narrative. The PLS and Consent to participate explained that only the researcher would have access to the data and that this data would be stored securely for five years at the University of Melbourne after which time it will be destroyed.

Paying careful attention to these risks ensured that the narrative inquiry approach used in this study provided a way of thinking about the challenges for STEM education in the Australian context by drawing on the stories of selected participants.

### 3.1.3 Method

The narrative inquiry approach was particularly suited to this study as it sought to build an understanding of how the participants conceptualised STEM education through recording and analysing their responses from the Delphi study and the semi-structured interviews. The relationship between each participant's conceptualisation of STEM education and their preferred choice of vision for STEM education in the Australian context was presented as a narrative. Exploring the opinions and ideas that emerged will suggest what successful implementation of STEM education would look like and the opportunities it may provide in the Australian context that previous initiatives or programs in education have not. In this

study, the narrative inquiry approach accommodated the presentation of the findings in summary tables and more expansively, with the use of quotes from the participants, to illustrate and explain their responses.

The narrative constructed in this study allowed the researcher to acknowledge the unique experiences of the participants by giving them a voice in the framing of the likely challenges for STEM education in the Australian context. This ascribed a richness and authority to the construction of narrative from a perspective of time and within a societal context.

### 3.1.4 Declaration of the researcher's stance in this study

My stance in this study is both as a researcher and as a participant due to my specific interest in curriculum, experiences as a science teacher and educator of preservice secondary science teachers and as a bureaucrat as a regional project officer and at the state level as a F-12 Science curriculum manager and manager F-10 curriculum (1976-2019). My stance was also influenced by my experiences as a school student from the late 1950s-to the early 1970s and as an undergraduate science student (1972-1975). It has also been shaped by my experiences in completing postgraduate studies in education (1990s and 2012-2020).

Bruner (1986) drew a distinction between stance and the negotiation of this stance for the researcher undertaking a narrative inquiry. As the researcher, I was seeking to understand the introduction and implementation of STEM education in the Australian context. This became my negotiated stance. Telling the stories of those who have contributed to education and were interested in STEM education enabled me to show that I cared about education and wished to contribute to education research. This became my stance. Given my longevity in education, it was likely that I would be known to some of the selected participants or that we may have mutual colleagues. This should assist me to gain the trust of the selected participants to tell their stories accurately Bruner (2012), Clandinin and Caine (2013) and Pinnegar and Daynes (2007). My study could be presented as communicating the participants' opinions about STEM education in the Australian context to a broader audience and to possibly generate further debate and discussion.

With my experiences in education, it is likely that I would have lived with and in the stories as these were recalled by the selected participants. Clandinin and Connelly (2000) referred to this as the continuing process of narrative inquiry. In this study, as the researcher, I will have moved between my narrative and that of the participants, whilst simultaneously

thinking about the past, present and future. This also enabled me to manage the tensions between the principles and the goals of narrative inquiry as identified by Daiute (2014).

In this study, the capturing of the education memory through the use of a narrative to better understand where we may go next with the implementation of STEM education in the Australian context was important. This equated to setting boundaries for the narrative as discussed by Clandinin and Rosiek (2007). In this study, as the researcher, I listened to and recorded the stories of the participants whilst I recalled my own narrative. This led to a mutual relationship from which a narrative would emerge to provide a snapshot of STEM education in the Australian context now and possibly into the future.

In this study, the selection of the documents and the participants in this study was influenced by my interests and experiences. My stance influenced the construction of the questionnaires and the analysis of data from the Delphi study. This, in turn, would likely have influenced the development of the possible visions for STEM education in the Australian context presented in the Delphi study. Similarly, the construction of the questions asked in the semi-structured interviews, the analysis of the transcripts of the interviews and the selection of the participants' quotes used to illustrate and support the findings from this study were influenced by my stance.

In adopting a narrative inquiry approach to present this empirical qualitative research, addressing validity and reliability became an issue. Rapley (2011: p.128) argued that these two terms could be replaced with "crisis of representation and crisis of legitimacy".

*Crisis of representation* referred to the different ways in which knowledge and academic texts were now constructed and how these have moved from the expression of facts to a collection of diverse opinions and responses. In this study, this was illustrated with the use of quotes as data and to support the analysis of the data in the findings from the Delphi study and the semi-structured interviews. The discussion of and the conclusions drawn from the findings also included representations of the researcher's reflection of their stance.

*Crisis of legitimacy* related to the evaluation of the truthfulness of the analysis of the data in qualitative research. Rapley (2011) argued that with the possibility of multiple opinions or responses being provided, new approaches to assess the quality of research were being used. In this study, to test the truthfulness of the analysis of the data from the Delphi study, an additional small group of participants (referred to as Non-Delphi study participants) were selected to participate in the semi-structured interviews. The Non-Delphi study

participants were asked questions related to the findings from the Delphi study to provide additional data for analysis and comparison.

In declaring my stance, I have acknowledged my position in this study and have identified and mitigated potential issues that could impact on the credibility of the study to ensure the quality of the narrative inquiry approach was maintained.

## 3.2 Document analysis

### 3.2.1 Introduction

Document analysis was used in this study as it provided a method that combined elements of content analysis relevant to the research questions and thematic analysis to construct categories to validate the data collected. Document analysis was the first phase of the empirical qualitative research undertaken in this study. It would be followed by a Delphi study and semi-structured interviews with selected participants.

The documents selected for analysis in this phase of the study were related to the introduction and implementation of STEM education internationally and in Australia. The selected documents were a representative sample of the published authority and included policy statements, reports and programs.

The document analysis undertaken in this study had three purposes. First was to identify the relationship to or impact of the documents on the introduction of STEM education and to determine the authorship, status and the intended audience of the documents. Second was to identify the key people and organisations who have contributed to the design of curriculum and education policy, particularly in Australia or who were now seen as members of the STEM education community in Australia or as having an interest in STEM education. Third was to determine if there was a consistency of vision, purpose and outcomes in the documents as the implementation of STEM education was expected to achieve.

### 3.2.2 Research questions to be addressed by the document analysis

1. What common themes were evident in the documents selected as being representative of the published authority?
2. How do these themes relate to the phases of curriculum as presented in the Curriculum development framework?

### 3.2.3 Purpose

Bowen (2009) defined document analysis as "a systematic procedure for reviewing or evaluating documents - both printed and electronic (computer- based and Internet-transmitted) material" (2009: p.27). Bowen (2009) likened document analysis to other types of analytical research that required "data (to be) examined and interpreted in order to elicit meaning, gain understanding and develop empirical knowledge" (2009: p.27) and argued that a procedure for analysing the documents consisted of "finding, selecting, appraising (making sense of), and synthesising data contained in documents" (2009: p.28).

Bowen (2009: p.29) further argued that examples of data from the document analysis also included excerpts or longer passages or quotations and that institution or organisational documents be extended beyond government policy documents to include reports, program proposals and media releases.

In this study, the five specific uses of documents described by Bowen (2009 pp.29-31) were used to support the development of the criteria used to select and to analyse these selected documents. The first of these was to provide background to and context for development and publication of the document to identify the status and the context of the documents selected and whether the document related to introduction or implementation of STEM education. The second was to track changes in documents from iteration to iteration. This was not directly applicable to this study as the documents selected were the final published versions. In this study, the slight variations or nuances in policies related to the introduction and implementation of STEM education released by the respective Australian governments were investigated. The third was to verify or corroborate the findings from other data sources and build trustworthiness and credibility. In this study, this was achieved by the selection of documents from both international and Australian governments and education authorities and from the different groups or stakeholders from the published authority interested in STEM education and to compare these with the findings from the Delphi study and the semi-structured interviews. The fourth was to generate supplementary data to identify other relevant documents or sources of information. In this study, documents related to STEAM and several sample programs for implementing STEM education internationally and in Australia were added to the list of documents analysed. The fifth was to provide background information to construct possible questions to be asked in the Delphi study and to be further explored in the semi-structured interviews undertaken in this study.

Codd (1988: pp.235-247) argued that the type of language used in policy documents and how this language was used mattered and should also be interrogated. Codd (1988) also argued that this use of language became the vehicle of power and an instrument to bring about the desired change or impose a specific political agenda. In this study, the language used in the selected documents and the status of the author or commissioning agency that was responsible for this change of the document were considered when analysing the selected documents. An example of a change in the language used was the shift away from the use of the term *race* to the use of indigenous or first peoples. Codd (1988) also suggested that the language used in policy documents was reflective of the times or contexts in which specific documents were published. In this study identifying the date of the publication and the prevailing political, economic and social context and the type of language used was included in the set of criteria developed to analyse the documents selected.

Bowen (2009: pp.31-32) further argued that document analysis was a valid research method for providing empirical data and, when combined with semi-structured interviews as undertaken in this study, limited researcher bias whilst maintaining credibility of the interpretation of the data. However, Bowen (2009) also cautioned that whilst there are advantages to using document analysis, disadvantages and limitations exist that should be recognised and minimised as:

> These are really potential flaws rather than major disadvantages. Given its efficiency and cost-effectiveness in particular, Document analysis offers advantages that clearly outweigh the limitations. (2009: p.32)

In this study, to minimise the limitations of document analysis, the five areas identified as necessary to provide the critical scrutiny of documents as proposed by Coffey (2013: pp.371-375) were used to support the development of a set of criteria to analyse the documents selected. These areas were authorship and leadership, the function of the document, the intended meaning and application, the audience and readability and interpretation of the document.

In this study, a set of criteria to analyse the selected documents was developed drawing on the work of Bowen (2009), Codd (1988) and Coffey (2013). The first criterion was the consideration of the status of the author and their position, for example, governments or professional associations or business or industry groups or academic researcher and the impact this had on how STEM education was positioned or represented.

The second criterion was the context for the publication, for example, the political, economic and social response to the changing nature of industry or the response to the results of student achievement on national and international tests. An example of a response from the political context was the requirement to have set standards to assess student achievement. This was illustrated by the inclusion in the Australian Curriculum of specific achievement standards in each learning area and for each level from Foundation to level 10.

The third criterion was the function of the document, the language and the type of language used and its readability as related to the intended audience. For example, the language used on a poster to inform students and parents about the careers and employment that required studies in STEM would be very different from a document for schools and teachers that related to the reporting of student progress and achievement in a systematic and formalised way.

The fourth criterion was the interpretation of what was the intended outcome of the document. For example, the design and use of assessment tasks that drew on knowledge and skills from across the STEM disciplines that would lead to increased enrolment in senior secondary science and mathematics subject in higher education STEM related courses.

The fifth criterion was the intended audience for the document, for example, the public or a specific interest group, or policy and curriculum writers or school leadership teams or developers of resources.

Rapley (2007: pp.109-110) added a further caution for researchers undertaking document analysis. Rapley (2007) also argued that it was important for the researcher to acknowledge the role of their own context and knowledge and experiences in the selection and interrogation of the documents and to understand how this may have impacted on the analysis and any conclusions drawn. In this study, the researcher developed and applied a set of criteria to select and analyse the documents and declared and reflected on their stance to mitigate the issues related to the credibility of the documents selected for analysis.

### 3.2.4 Application of the document analysis

Document analysis is not without risk and maintaining the researcher's ability to understand the purpose, context and intended audience of each document selected for analysis was critical. The researcher was acting as a subjective interpreter of the selected documents. This required that the processes used to analyse the documents were transparent and rigorous (Bowen 2009). In this study, the detailed analysis of twelve of the thirty-two

selected documents has been included in the next chapter to provide examples of transparency and rigour of the document analysis undertaken.

An advantage of using document analysis in this study was the open and ready access to the selected documents. The use of the internet provided easy, quick and cost-effective access to documents available in the public domain, for example, government policies, online journals and media releases. Where the selected document was not available online, these were sourced in the original print copy from libraries and parliamentary archives. The stability over time of the published documents also enabled reliable access to documents that chronicled factors impacting on education at a specific time or in a specific context including curricula or assessment practices or government initiatives. The findings from the analysis of the data were used to address the two research questions specific to the document analysis.

In this study, the two potential disadvantages or limitations in using document analysis were low retrievability and biased selectivity (Bowen 2009). Low retrievability was mitigated by the use of library and internet searches for relevant documents from the published authority. All the documents selected were available either in electronic format or in print copy, so access to any of these was not blocked.

In this study, biased selectivity resulting from the stance of the researcher was mitigated by undertaken the following five steps. First was to draw on the literature review to develop a set of selection categories to determine which documents were selected and analysed. Second was the selection of multiple documents that fulfilled at least one of the selection categories. Third was stating and acknowledging my stance as the researcher. Fourth was the selection of documents from multiple sources within the published authority. Fifth was where the author of the original document was unavailable, further clarification and information about the document was sought from other sources.

### 3.2.5 Selection of documents

In this study, to maximise the advantages and minimise the disadvantages of document analysis, a set of categories was developed and used to provide a range of relevant documents for analysis. This was done to address the rigorous analysis that Bowen (2009) and Coffey (2013) argued was necessary and to facilitate an investigation of the type, use and context of the language in the documents as discussed by Codd (1988) and Rapley (2007). In this study, the emphasis was placed on the quality of the documents selected rather than the selection of a specific number of documents (Bowen 2009: p.33). The types of documents selected for

analysis in this study were sourced internationally and from Australia, were available in electronic and print formats and were related to the implementation of STEM education programs, curriculum and research regarding to the introduction and implementation of STEM education. All documents were published in English.

From chapter two, the following themes would likely be present in the documents selected for analysis:

- social: addressing and/or improving access and equity of access to education, careers and employment for all citizens regardless of gender, cultural, indigenous or socioeconomic status;
- prosperity of the nation and community through sustained economic growth and social cohesion;
- political: for example, new governments with different ideology or focus on improvement in student performance and ranking on international tests and local tests or accountability of funding expended on education;
- economic: growth and global competitiveness with shifts in the base of economy over time, the lack or limited supply of an appropriate workforce to grow the economy;
- required knowledge and skills: transferability of skills from old to new industries and jobs in STEM and STEM related fields;
- new stakeholders or new research in STEM education.

In this study and drawing on this information, five categories for the selection of documents were developed and used. The first category developed included published curriculum documents related to policy, content and structure. This enabled the identification of the context for changes in the direction of curriculum development and the knowledge and skills included, the introduction of new initiatives in education and the existence of any indicators of the introduction of STEM education. The nature and influence of the political, economic or social context on the curriculum were also noted. This category corresponded to specific uses for document analysis to provide background and context, to generate other relevant documents and to provide questions for the Delphi study and the semi-structured interviews (Bowen 2009). It also accommodated the emphasis on the type of language (Codd, 1986 and Rapley, 2007).

The second category developed included publications that identified new approaches or trends in education particularly relevant to STEM education, for example the integration of the STEM disciplines in the curriculum and assessment tasks or pedagogical practices designed to increase student engagement or improved access to and equity of access to resources. This would provide examples of the contexts for and the outcomes or benefits expected from these new approaches. This category corresponded to specific uses for document analysis to provide background and context and to verify or corroborate the findings from other data sources (Bowen 2009). It also accommodated construction of timelines to show historical developments, contexts and use of language (Rapley 2007) and an approach to establish meaning and building knowledge (Altheide 2000).

The third category developed included international, national and state government policies and reports that led to the introduction and implementation of STEM education in specific jurisdictions. This included the status of the authors of the documents, the level of input from stakeholders and the expected education outcomes. This category corresponded to specific uses for document analysis to provide background and context, to generate other relevant documents and to provide direction or questions for the Delphi study and the semi-structured interviews (Bowen 2009). It also investigated how particular groups construct documents, as emphasised by Coffey (2013), and the importance of the type of language used, as suggested by Codd (1988) and Rapley (2007).

The fourth category developed included published research related to curriculum, pedagogy and assessment policies and practices associated with the implementation of STEM education in the Australian context. This category corresponded to specific uses for document analysis to verify or corroborate the findings from other data sources (Bowen 2009) required to build trustworthiness and credibility of the analysis (Rapley (2007) and to generate supplementary data to identify other relevant documents or sources of information.

The fifth category developed included published reports from stakeholders other than governments that provided responses to or sought to influence government policies and initiatives. This included reports from, for example, Engineers Australia (EA) and UNESCO. This category corresponded to specific uses for document analysis to verify or corroborate the findings from other data sources to build trustworthiness and credibility of the analysis and to generate supplementary data to identify other relevant documents or sources of information (Bowen 2007). This category also focussed attention on the authorship, function

and audience (Coffey 2013). The focus of each of the five categories is summarised in Table 3.1.

**Table 3.1 Summary of the categories for the selection of the international and Australian documents**

| Category | Focus |
|---|---|
| 1 | Published curriculum documents related to policy, content and structure. |
| 2 | New approaches to or trends in education relevant to STEM education including curriculum, assessment and pedagogy. |
| 3 | International and Australian Government policies and reports that led to introduction and implementation of STEM education. |
| 4 | Published research related to curriculum, pedagogy and assessment policies and practices associated with STEM education. |
| 5 | Publications from other stakeholders. |

### 3.2.6 Procedure

From the internet search and using the five selection categories, thirty-two documents were selected, read and annotated. Each of the thirty-two documents selected was firstly skimmed to determine its status and how it positioned STEM education. Next, the type of document, for example, policy or implementation program or report of research and its focus or relevance to the research questions, was noted. Then a detailed reading of each document was undertaken and annotations were made on each document identifying key points or expected outcomes, with any references to other published documents noted. The availability of and access to the documents was recorded, for example as hard or electronic copy or open or limited access.

The annotations made on each document were used to determine if there was consistency between the documents as to the rationale for the introduction of STEM education and if there was a common understanding of the purposes of and requirements for its implementation. Any monitoring or evaluation strategies to assess the effectiveness of any new STEM education initiative or program included in the documents were also noted and further investigated. The annotations made on each of the thirty-two documents analysed were used to identify any common themes.

### 3.2.7 Data analysis

In this study, a set of protocols for the data analysis that included the development of categories to select the documents and a set of criteria for the analysis of the selected documents to identify and present the emergent themes was used. The use of the set of protocols was in response to the work of Altheide (2000: p.290) who proposed that "qualitative data analysis was similar to all qualitative methodology" because both focus on exploring and developing understanding of an idea or initiative or problem. Altheide (2000: pp.287-299) also argued that qualitative data analysis was interpretive and empirical and as such provided information from a specific point in time rather than leading to broader generalisations that were applicable to the wider population. Altheide (2000: pp.292-293) further emphasised that conducting qualitative data analysis included the development and application of protocols.

Using the set of criteria developed to analyse the documents the annotations made on each selected document related to the status of the document and its author, publication date and where applicable the lifespan, for example, a strategy plan for the next five years, the use of terms or style of the language used, the political, economic or social context, the key points, the expected outcomes and the intended audience.

The analysis identified what was common to all or some of the documents or was unique to a particular selected document. From this analysis, a list of themes was constructed. These themes were compared to those from the literature review, to determine if the themes were representative of all groups represented in the published authority or were common to a specific group or groups within the published authority. The relationship between the themes and the phases of the curriculum development framework was also investigated.

## 3.3 The Delphi study

### 3.3.1 Introduction

When education is viewed as a people industry reliant on communication between all involved, then establishing agreed understandings of the purposes and directions of an education reform is critical to ensuring the effective implementation of the reform. How a group of Australian participants conceptualised STEM education and how this influenced the choice of a preferred vision for STEM education in the Australian context was investigated using a Delphi study.

In this study, the application of a Delphi study with its focus on communication through structured discussions and decision making was pertinent because it was used to gather the opinions and ideas of the selected participants who through their interests and experiences and their current or past positions have a long history in influencing and contributing to the development of education policies and programs in Australia. The analysis of data from the Delphi study provided questions that were further explored in the semi-structured interview.

### 3.3.2 Research questions to be addressed by the Delphi study

1. What are the purposes for STEM education and the requirements for its implementation in the Australian context as identified by selected participants?
2. How do the selected participants conceptualise STEM education?
3. Do the selected participants have a preferred vision for STEM education in the Australian context?

### 3.3.3 Purpose

Linstone and Turoff (1975) explained the use of the Delphi study as an appropriate tool to investigate how groups deal with complex problems because:

> Delphi may be characterised as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem. (1975: p.3)

In this study the complex problem was building an understanding of STEM education that was useful for its implementation now and meaningful for the future. Linstone and Turoff (1975: p.4) argued that the Delphi study (sometimes referred to as the Delphi technique) was applicable to research that sought to gather the personal beliefs and views of selected individuals to determine if a group opinion or understanding existed that would be useful in providing answers to current questions or directions for future inquiries. Linstone and Turoff (1975: pp.564-586) also identified and discussed in detail *eight basic pitfalls* of the application of a Delphi study that would impact on the credibility of the analysis of data collected and any conclusions drawn.

Linstone and Turoff (1975: p.5) also presented reasons as to why the application of a Delphi study could fail, including the imposition of the researcher's views by structuring the questions in a particular way or style, the assumption that the Delphi study was the only communication tool that could be used to gather data to address the research questions, poor

summarising, interpretation and evaluation of the data provided, ignoring or not exploring disagreements or differences and underestimating the demanding nature of the Delphi study and the commitment required by participants and that a participant may not complete all questionnaires included in the Delphi study. Linstone and Turoff (1975: p.5) also suggested that, whilst it was not possible to eliminate all problems associated with conducting a Delphi study, the application of transparent processes would ensure that the impact of these problems was managed appropriately.

In a more recent publication, Linstone and Turoff (2011: pp.712-1719) in reflecting on the development and use of Delphi since the 1950s, reminded researchers currently using a Delphi study that the aim is not to reach consensus "but rather in alerting the participants to the complexity of issues" (2011: p.1714) and to "challenge to concepts and underlying assumptions" (2011: p.1714).

In reflecting on the growing use of the Delphi study, Linstone and Turoff (2011) were gently alerting researchers that it was acceptable if a group opinion or understanding was absent as this signalled that further investigation would be valuable. Linstone and Turoff (2011) also acknowledged that the access to and use of online communication tools and collaboration sites would likely support further evolution of the use of the Delphi study in research and stressed that researchers must remain vigilant to ensure the integrity of their study.

Hasson and Keeney (2011: pp.1695-1704) argued that the *trustworthiness* of the analysis of data from the Delphi study could be enhanced by conducting interviews with a group of a participants who did not undertake the Delphi study. These participants would have similar experiences to those who completed the Delphi study and could corroborate or challenge the analysis of data from the Delphi study and would add trustworthiness to the findings recorded. Rowe and Wright (2011: pp.1487-1490) also raised similar concerns related to the establishment of rigour or trustworthiness, reliability and validity associated with the use of a Delphi study in qualitative research.

#### *3.3.3.1 Transitioning to the Delphi study conducted in this study*

In this study, the concerns expressed by Hasson and Keeney (2011) and Rowe and Wright (2011) were addressed as follows:

> Step 1: decisions about which participants were selected and how contact with them would be established and maintained were documented.

Step 2: prior to beginning the Delphi study, a pilot of the structure and content of the first two questionnaires was conducted with colleagues of the researcher with a background in science and mathematics education and language studies. The feedback provided was used to improve the layout and clarity of the instructions and the questions on the questionnaires.

Step 3: the declaration of the researcher's stance, including the identification of any areas of likely bias and the acknowledgement of any connections to the possible participants.

Step 4: the researcher's interpretations and analyses of the de-identified data from the first two questionnaires was visible to the participants in the questions presented in the subsequent questionnaires of the Delphi study.

Step 5: reminder emails as necessary and updates were sent to participants to maintain their active involvement in the Delphi study.

Step 6: an audit trail of all contact with participants including references to any documents suggested by participants as supporting a specific point of view or offering an alternative opinion that may be of interest or relevant or useful to the study.

Step 7: a consistent length of time was given to complete and return each questionnaire and between the release of each questionnaire.

Step 8: the investigation of the findings from the Delphi study with a small group of like participants in separate semi-structured interviews was undertaken to determine the trustworthiness of the findings.

Linstone and Turoff (1975) suggested that there were four phases in a Delphi study. In this study, phase one was the gathering of information about STEM education in Questionnaire 1. The second phase was the identification of any areas of agreement and disagreement from Questionnaire 1 to build an understanding of the opinions expressed by the participants in Questionnaire 2 related to STEM education in the Australian context. The third phase was the deeper investigation of any differences identified in the responses from Questionnaire 2. The fourth phase was the explanation of choices the participants made in Questionnaire 3.

In this study, participants would have a high level of training and competence in the specialised knowledge related to experiences in STEM education or the STEM disciplines or

curriculum development or pedagogical and assessment practices or education policy or education research as recommended by Hsu and Sandford (2007: p.3).

### 3.3.4 Application of the Delphi study

The use of the Delphi study enabled the selected participants to remain anonymous and to record and share their understanding, opinions and responses to specific questions related to STEM education in the Australian context. It also provided participants with the opportunity to reflect on past reforms in education and to speculate about the future of STEM education. The use of electronic questionnaires in the Delphi study enabled the speedy distribution and return of the questionnaires, allowed the participants to complete the questionnaires at a time convenient to them and supported the inclusion of participants from across Australia, as it eliminated the costs associated with meeting face to face or using video conferencing across different time zones.

In this study, when designing the questionnaires for the Delphi study, careful attention was paid to addressing the pitfalls and mitigating the possible causes of failure identified by Linstone and Turoff (1975) that could limit the usefulness and quality of data obtained from a Delphi study.

#### *3.3.4.1 Addressing the pitfalls identified by Linstone and Turoff in this study*

There were two groups of pitfalls one related to the selection of participants for the Delphi study and the other related to how the Delphi study was conducted (Linstone and Turoff, 1975: pp.574-586). The pitfalls related to the selection of the participants and included discounting the future, deception, optimism-pessimism bias and overselling. The pitfalls related to conducting the Delphi study included prediction urge, simplification urge, illusory urge and sloppy execution.

In this study, the pitfall of discounting the future (1975: pp.574-578) was addressed by the selection of participants with a longevity in education who were able to reflect on past education reforms and look beyond the current reforms to suggest future reforms. The pitfall of deception (1975: pp.585-586) was addressed in the publication of the criteria used to select the participants for the Delphi study. The pitfall of optimism-pessimism bias (1975: p.584) was addressed by accepting that some of the participants would likely be optimistic about STEM education and others would likely be pessimistic and that this would not diminish the value of their responses, as each set of responses was treated as being of equal value. The pitfall of overselling (1975: pp.584-585) was addressed in the acknowledgement that

presentation of the data and findings was from a specific group of participants and their perspectives at a specific time.

In this study, the prediction urge (1975: p.578) related to structuring the questionnaires to accommodate a diversity of opinions rather than directing responses in a specific way. The simplification urge (1975: pp.579-581) related to accommodating differences in opinions rather than enforcing consensus. The illusory urge (1975: pp.581-582) related to providing opportunities for participants to discuss what has impacted on their responses. The use of open-ended questions on the first questionnaire and the opportunity to explain choices made on the second and third questionnaires enabled the participants to demonstrate their level of expertise, understanding and opinions of STEM education in the Australian context. This approach to the construction of the questionnaires used in the Delphi study limited the impact of the pitfall of prediction, deception and illusory urges. The sloppy execution urge (1975: pp.582-583) was addressed by using established processes for the construction and distribution of the three questionnaires and to record and analyse the data collected to ensure the anonymity of the participants.

In this study, the criteria developed for the selection of participants drew on the literature review and the findings from the document analysis. Publication of the selection criteria and the reasons for the inclusion of the participants was done to enhance the credibility of the analysis of the data. Using these selection criteria, potential participants were identified, contacted by phone or email and invited to participate.

As STEM education is often presented as a political and economic solution to growing a nation's economic prosperity, the selection of participants with a history in education reforms who could reflect on the success or otherwise of past programs was important. These participants would be well placed to identify the requirements for sustainable STEM education programs beyond the short electoral cycles and the politically expedient quick fixes for issues related to educating young Australians now and into the future.

#### *3.3.4.2 Mitigating the failures identified by Linstone and Turoff in this study*

To mitigate underestimating the demanding nature of the Delphi study, the commitment required by participants and managing the non-return of questionnaires the following process was implemented (Linstone and Turoff, 1975: p.5). First was the use of the Plain Language Statement (PLS) and Consent to participate that identified and explained the tasks to be completed and the time commitment required. This included giving participants two weeks to

return the completed questionnaires, with two to four weeks between each questionnaire to maintain interest and momentum and for the completion of the analysis of data and the construction of the subsequent questionnaires. After the initial phone conversations with the participants seeking their interest and willingness to participate in the Delphi study, all further communication with participants was via email.

Second, in order to mitigate poor summarising, interpretation and evaluation of data and to ensure disagreements and differences were explored and not ignored, regular meetings with the researcher and their academic supervisors were scheduled to discuss the de-identified data analysis. To further enhance the quality and credibility of the Delphi study, summaries of the findings were presented at Australian and international conferences.

Third was the use of the feedback from the pilot study conducted and from the regular meetings between the researcher and their academic supervisors to mitigate the imposition of the researcher's views in structuring the questions in a specific way or style or in the analysis of the data.

Fourth was the use of open-ended questions, where participants were encouraged to elaborate on their responses to mitigate the assumption that the Delphi study was a communication tool that only accommodated a single response. This approach provided a rich data set that informed the construction of the subsequent questionnaires and that would be further explored in the semi-structured interviews with participants. It also mitigated the impact of ignoring differences in the participants' responses.

### 3.3.5 Selection of participants for the Delphi study

The selection criteria were developed from the literature review and the document analysis and were used to compile a list of potential participants for inclusion in this study. In this study, each participant invited to participate would be able to provide a breadth of experiences, opinions and ideas and would fulfil more than one of the selection criteria developed. It was also expected that the participants had expressed an interest in STEM education through their position or publications or research literature or keynote lectures and seminars or also had expertise in curriculum, pedagogy or assessment.

#### *3.3.5.1 Selection criteria developed and applied in this study*

The selection criteria developed consisted of five overarching categories. First was a history or record of achievement in research or publications in Australia or internationally,

with a focus on contributions to education in one or more of the disciplines of STEM and/or in education in general and in curriculum, assessment or pedagogy specifically (Category 1). Second was influence and longevity of influence and status with peers and within STEM education and education in general (Category 2). Third was a list of contributions to the public debate related to STEM education, provision of advice, reports or policy direction to governments (Category 3). Fourth was as an advocate or critic of STEM education and who as such were able to discuss how they arrived at their current position on STEM education and possibilities and concerns for the future of STEM education (Category 4). Fifth was as a representative of government or professional organisations or associations, or business or industry or philanthropic organisations (Category 5).

From these five categories a list of twenty-one selection criterion was constructed. This data are presented in Table 3.2.

**Table 3.2 Category and selection criteria for the Delphi study participants**

| Category | Selection criterion number and title |
|---|---|
| 1 | 2. Published researcher; 3. Published author (book/chapter/editor); 11. Pedagogy; 12. Access and equity- gender; 13. Access and equity- indigenous;14. Access and equity- rural/regional; 15. Assessment; 16. Curriculum; |
| 2 | 1. Discipline at least one of S, T, E, M; 4. Educator in discipline; 7. Leadership - faculty/department/organisation; 8. Leadership – program; 9. Leadership- other |
| 3 | 10. Policy developer/writer; 17. Resources development/publications; 18. Professional development for pre and post service educators |
| 4 | 19. Educator in STEM; 21. Media contributor |
| 5 | 5. Statutory Authority; 6. Business/Industry; 20 Other; |

As the context for this study was STEM education in Australia, all participants selected were from Australia. The profile for each of the Delphi study participants is shown in Table 3.3.

**Table 3.3 Profile of Delphi study participants in response to the selection criteria***

| Selection Criteria/Participant | A | B | C | D | E | F | G | H | K | L | P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Discipline at least one of S, T, E, M | ✓ | ✓ | | ✓ | ✓ | | | ✓ | ✓ | | |
| 2. Published researcher | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 3. Published author (book/chapter/editor | ✓ | ✓ | | ✓ | | ✓ | ✓ | | ✓ | ✓ | |
| 4. Educator in discipline | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 5. Statutory Authority | | | | | | | | | | | ✓ |
| 6. Business/Industry | | | | | ✓ | | | | | | ✓ |
| 7. Leadership-faculty/department/organisation | ✓ | ✓ | | | ✓ | ✓ | ✓ | | ✓ | | ✓ |
| 8. Leadership – program | | | ✓ | ✓ | | | ✓ | ✓ | | | |
| 9. Leadership – other | ✓ | ✓ | | | ✓ | | ✓ | | ✓ | ✓ | ✓ |
| 10. Policy writer/developer | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| 11. Pedagogy | ✓ | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ |
| 12. Access and equity – gender | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | | |
| 13. Access and equity – indigenous | | | | ✓ | | | | | | ✓ | |
| 14. Access and equity – rural/regional | | | | ✓ | | | | | ✓ | | ✓ |
| 15. Assessment | ✓ | ✓ | | | | | | | ✓ | | ✓ |
| 16. Curriculum | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ |
| 17. Resources development/publications | ✓ | ✓ | | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ |

*four of the eleven participants were female

*3.3.5.2 Examples of the profile of participants and their match with the selection criteria.*

Example 1

Imagine a participant who began as a teacher with qualifications in science, who then undertook further study and became an academic, who pursued research with a focus on teacher education in particular areas leading to numerous publications in journals and chapter contributions to books, who completed reports for governments and presented keynote

addresses at national and international conferences. This participant would then address criteria 1, 2, 3, 4, 7, 9, 11, 16, 17, 18, 21.

Example 2

Imagine a participant who having completed a higher research degree in one of the disciplines of STEM, worked in industry and then moved to academia to undertake teaching in undergraduate courses and to pursue research in partnership with government and industry and who assumed a leadership position in a professional association. This participant would then address criteria 1, 2, 3, 4, 6, 7, 9, 15, 16, 19, 21.

Example 3

Imagine a participant who moved from teaching but not in the STEM disciplines, to the design and development of curriculum and assessment including resourcing professional development programs, to commissioning research and benchmarking reports to evaluate existing curriculum and assessment programs, to presenting reports on international trends in education to and on behalf of governments, who partnered with business and industry to implement significant education reforms and led organisations through periods of change. This participant would then address criteria 3, 5, 7, 10, 11, 14, 15, 16, 17, 20.

In this study, the development, use and publication of the criteria for the selection of participants addressed and minimised the issues of transparency and the limitations of the application of the Delphi study as discussed by Linstone and Turoff (1975, 2011), Hasson and Keeney (2011) and Rowe and Wright (2011).

### 3.3.6 The Instrument

In this study, there were eleven participants and three iterations (or rounds) for the Delphi study. This was consistent with the arguments presented by Linstone and Turoff (1975: pp.229-235) that three iterations provided a stability of responses with little if any change occurring in the additional rounds and that a sample size of ten plus participants was appropriate.

The first iteration, Questionnaire 1, gathered opinions and ideas. The eleven participants were asked to respond to three open-ended questions related to the purpose of STEM education, the requirements for implementation of STEM education and how they would explain STEM education to ‘non-STEM’ people.

The second iteration, Questionnaire 2, asked the participants to respond to two questions. The first question was to rank a list of statements related to the purpose of STEM education from 1 (most preferred) to 7 (least preferred). The second question was to assign a level of priority to a list of requirements for the implementation of STEM education from 1 (high) to 5 (low) and the level of priority able to be used more than once. The purposes and requirements included were constructed from the analysis of the data from Questionnaire 1

The third iteration, Questionnaire 3, asked the participants to respond to two questions. The first question was to choose a preferred vision for STEM education in the Australian context from the list provided. The visions were constructed from the analysis of data provided from Questionnaires 1 and 2. There was also an option provided for participants to amend the wording of the vision they chose. The second question was to select three pivotal statements that were required to implement their preferred choice of vision from the list provided. There was also an option provided to participants to construct their own pivotal statement.

Each of the three questionnaire allowed participants to provide additional comments. The analysis of the responses from each questionnaire is presented and discussed in chapter five. A copy of each questionnaire is included Appendix 2.

#### *3.3.6.1 Explanation of the construction of Questionnaire 1*

In the first iteration of the Delphi study, the questions were open-ended and designed to capture the opinions and ideas of the participants.

Q1. What do you believe is the purpose(s) of 'STEM education'?

This question was seeking to determine if and which themes identified from the document analysis were evident in the responses, if the responses were reflective of the participant's position or stance or experience and if drivers for STEM education, for example economic growth or future workforce were evident in the responses.

Q2**.** Given the purpose(s) of STEM education you identified in Q1 what is necessary/required to achieve/implement this purpose(s)?

This question sought to investigate what was needed to implement STEM education, the relationship between the purposes and the requirements for its implementation and if the responses were reflective of the participant's position or stance or experience. It also led to

the development of a question seeking advice about the future of STEM education that was asked later in the semi-structured interviews.

Q3**.** How would you explain STEM education to someone who is not familiar with this term?

This question investigated what messages were needed to inform people about the essence of STEM education from those working with or with an interest in STEM education.

Q4 Any additional comments

This provided the opportunity for participants to supply additional information or comments.

*3.3.6.2 Explanation of the construction of Questionnaire 2*

In the second iteration of the Delphi study, the participants were able to see what other participants were thinking about STEM education and how their individual responses from Questionnaire 1 were analysed to construct the Questionnaire 2.

The responses from Questionnaire 1 were first analysed (refer 5.1) and then used to construct the list of purposes for STEM education and a list of requirements for its implementation on Questionnaire 2. These were designed to reflect the similarities, differences and uniqueness of the responses from Questionnaire 1. Questionnaire 2 was designed to determine which purposes were ranked more highly and which requirements were given a higher priority. Of equal importance was to determine if the reasons a participant gave for their responses were shared with other participants.

Q1. Responses to Q1 on the purpose(s) of STEM education on the Questionnaire 1 have been collated to form the list below. Please rank these from 1 to 6 where 1 is the most important for you and 6 is least important for you.

*Purpose 1: equip people with the knowledge and skills necessary to drive economic and social prosperity in the 21$^{st}$ Century technology rich workplaces and careers.*

This purpose combined curriculum as knowledge and skills, context as economic and social prosperity and future as twenty-first century technology rich workplaces and careers. It was underpinned by viewing STEM education as a political, economic and social enterprise and was a combination of elements from three purposes (a, c and d) that were identified from the analysis of data from Questionnaire 1.

*Purpose 2: build students' understanding of the world around them and how they can contribute to making it a sustainable place to live now and into the future.*

This purpose combined curriculum as foundational or essential knowledge and skills or capabilities with assessment to build students' understanding and engagement and access by giving students a voice in making their present and future sustainable. It was underpinned by viewing STEM education as consisting of curriculum, assessment and engagement and was a combination of elements from four purposes (b, c, d and e) that were identified from the analysis of data from question 1 on Questionnaire 1.

*Purpose 3: provide pathways for entry into the digital workforce and for the next generation of specialists in STEM fields.*

This purpose combined multiple modes of assessment and access as pathways and the specialised nature of the future workforce as requiring digital technology and specialists in STEM fields. It was underpinned by viewing STEM education as a political and economic enterprise and was a combination of elements from three purposes (a, d and e) that were identified from the analysis of data from question 1 on Questionnaire 1.

*Purpose 4: engage students with 'real-world problems' that require input from each of Science, Technology, Engineering, and Mathematics to solve.*

This purpose focussed on pedagogy and authentic learning to engage students with real-world problems requiring input from each of Science, Technology, Engineering and Mathematics. The four disciplines were presented as being of equal status with specific or fundamental knowledge or skills or dispositions required from each to solve the problem. It was underpinned by viewing STEM education as social engagement and was a combination of elements from four purposes (b, c, d and e) that were identified from the analysis of data from question 1 on Questionnaire 1.

*Purpose 5: improve access to careers in STEM fields for previously under-represented groups (for example girls/women, rural, indigenous).*

This purpose focussed on providing access and equity of access to opportunities for all students and hinted at community partnerships. It was underpinned by viewing STEM education as an economic, social and sometimes a political enterprise and was a combination of elements from two purposes (a and c) that were identified from the analysis of data from question 1 on Questionnaire 1.

*Purpose 6: introduce students to the use of evidence to make ethical decisions about contemporary and complex issues.*

This purpose referenced the use of the general capabilities from the Australian Curriculum as supporting student learning and their engagement in authentic and ethical decisions and social contexts that include contemporary and complex issues. It also directed attention to the types of pedagogy that include the use of evidence. It was underpinned by viewing STEM education as a social enterprise and was a combination of elements from two purposes (b and c) that were identified from the analysis of data from question 1 on Questionnaire 1.

Q2. Responses to Q2 on Questionnaire 1 (requirements for the implementation of STEM education in the Australian context) have been collated to form the list below. What level of priority, if any from 1 (highest) to 5 (lowest), would you assign to each one? Space has been provided for you to elaborate on your responses.

*Requirement 1: A shift from a focus of acquiring specific content knowledge to the achievement of outcomes where acquisition of skills has a greater importance in the development of curriculum and assessment tasks.*

This requirement sought to determine if a shift to skills was necessary or if both knowledge and skills could be accommodated and was linked to curriculum, assessment and access and equity of access and was a combination of elements from two requirements (b and c) that were identified from the analysis of data from question 2 on Questionnaire 1.

*Requirement 2: Sustainable partnerships between schools, universities, TAFEs and industry/business as applicable that support and collaborate on the delivery of high-quality STEM education in schools.*

This requirement focussed on the use of partnerships as a way to improve access and outcomes for students and to increase teacher competence and confidence in STEM education. This requirement also sought to investigate if a shared understanding was required for partnerships to be successful and sustainable. This was linked to access, curriculum, the future, shared responsibility and teacher quality and was a combination of elements from two requirements (a and b) that were identified from the analysis of data from question 2 on Questionnaire 1.

*Requirement 3: Use of age appropriate applied investigations and activities to demonstrate how knowledge and skills from multiple disciplines are used to solve problems.*

This requirement sought to determine if an emphasis on applications was necessary and was linked to access, assessment, pedagogy and working across disciplines and was a combination of elements from two requirements (a and b) that were identified from the analysis of data from question 2 on Questionnaire 1.

*Requirement 4: Develop a transdisciplinary approach to teaching and learning that incorporates the elements of STEM disciplines and draws from other disciplines as required to investigate issues important to students and community.*

This requirement sought to determine if a particular approach and an agreed understanding of what this approach looked like was necessary. This requirement was linked to pedagogy, students and their community and social cohesion and was a combination of elements from two requirements (a and b) that were identified from the analysis of data from question 2 on Questionnaire 1.

*Requirement 5: Development of a curriculum for Early Years to Year 12 that links learning areas (disciplines) in ways that support students to solve 'real world' problems.*

This requirement sought to determine if the inclusion of links between learning areas was consistent and required across all year levels in the curriculum. This requirement was linked to curriculum content and organisation and was a combination of elements from two requirements (a and c) that were identified from the analysis of data from question 2 on Questionnaire 1.

*Requirement 6: Building community understanding of the relationship between studying STEM subjects and future employment including supporting parents to become STEM aware.*

This requirement focussed on the contribution of the community in building a STEM skilled workforce through determining how STEM education and its relevance was understood beyond education settings. This requirement was linked to the political, economic and social drivers of STEM education and providing access to all community members (not just students) as referenced in requirements (a, b and c) that were identified from the analysis of data from Questionnaire 1.

*Requirement 7: Review of assessment requirements of senior secondary STEM subjects to accommodate projects completed using an inter-disciplinary approach.*

To determine if the implementation of STEM education was influenced by other factors such as external examinations and the use of the ATAR for selection to higher education.

(The ATAR is the Australian system that assigns a ranking to each student based on the marks achieved in subjects studied at the year 12 level). This requirement was linked directly to policies related to assessment and was a combination of elements from two requirements (a and c) that were identified from the analysis of data from question 2 on Questionnaire 1.

The inclusion of this requirement provided an opportunity to explore a unique response from question 2 on Questionnaire 1, where only one participant mentioned assessment. This was an example of how the Delphi study could be used to seek feedback from the other participants on assessment, which was one of the themes identified from the document analysis as being important to the implementation STEM education.

Following the construction of the six purposes and the seven requirements a matching exercise was undertaken to ensure that there was alignment between purposes and requirements as was evident in the responses provided by the participants on Questionnaire 1. The alignment data is presented in Table 3.4.

**Table 3.4 Alignment of the purpose of STEM education with requirements for STEM education**

| **Purpose** | **Aligned with Requirement statement(s)** |
|---|---|
| 1: equip people with the knowledge and skills necessary to drive economic and social prosperity in the 21st Century technology rich workplaces and careers. | 1, 2, 5 and 6 |
| 2: build students' understanding of the world around them and how they can contribute to making it a sustainable place to live now and into the future. | 1, 3, 4 and 5 |
| 3: provide pathways for entry into the digital workforce and for the next generation of specialists in STEM fields | 1, 6 and 7 |
| 4: engage students with 'real-world problems' that require input from each of Science, Technology, Engineering, and Mathematics to solve. | 2, 3, 4 and 5 |
| 5: improve access to careers in STEM fields for previously under-represented groups (for example girls/women, rural, indigenous). | 2, 6 and 7 |
| 6: introduce students to the use of evidence to make ethical decisions about contemporary and complex issues. | 3, 4 and 7 |

Q3 Any additional comments

This provided the participants with the opportunity to supply additional information or comments.

*3.3.6.3. Explanation of the construction of Questionnaire 3*

In the third iteration of the Delphi study, the participants were able to select a preferred vision from the three presented and three pivotal statements required to implement this vision from the list provided.

In constructing the visions for STEM education in the Australian context from the analysis of the data from the questionnaires one and two (refer 5.1 and 5.2 respectively), four principles were observed. First was that the vision statement was to be succinct and did not contain jargon that may not be accessible to or understood by the whole community. This reflected the comments made by some participants on the two previous questionnaires related to the use of jargon in education documents that was often confusing to the community. Second was that the vision statement was to be politically neutral. This reflected comments from some participants who had accepted the political context as one of the drivers of STEM education and wanted its development and implementation to be free of any government bias. Third was that the vision would look towards the future whilst remaining relevant to the present. This reflected the emphasis participants placed on the education that young people will require to manage the complex and challenging nature of the world they will face. Fourth was that the vision statement be able to guide the development of any strategic framework that includes aims or goals, targets or outcomes, timelines, resourcing and evaluation relevant to STEM education and its implementation. This reflected the need to be inclusive of the different purposes and the voices of those who see themselves as stakeholders in the STEM education and the approaches to implement STEM education as expressed by participants on the two previous questionnaires.

Q1. Three visions for STEM education in the Australian context are presented below. These visions have been constructed from the analysis of data provided by the participants in response to Questionnaires 1 and 2. Which vision best aligns with YOUR preferred vision for STEM education in the Australian context?

*Vision 1: STEM education contributes to a broad suite of learning experiences that enable all young people to participate in and contribute to building sustainable communities.*

This vision included breadth in learning to reflect the inclusion of disciplines other than the STEM disciplines as suggested by some participants in the two previous questionnaires. This vision had a focus on action as participation and building where young people were doers not passive acceptors or receivers and looked to the future living in a sustainable community. It brought together implicitly the economic and social contexts of the time in which STEM education has emerged as a priority.

*Vision 2: STEM education provides the skills that enable all young people to contribute to growing the nation's economy and global competitiveness.*

This vision suggested that young people need to acquire a specific skill set to ensure Australia's future prosperity within the context of economic growth and prosperity on the global stage. It assumed that all young people have access to and equity of access to the development of these skills.

It brought together the political and economic drivers and contexts for STEM education as identified by some participants in the two questionnaires. The emphasis was on the development and acquisition of STEM skills that contained an element of accountability in that young people have a role in and should take responsibility for their future.

*Vision 3: STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they live now and into the future.*

This vision included the acquisition of both knowledge and skills to assist young people to make sense of their world and to support them into the future.

Vision 3, unlike Visions 1 and 2, focussed on building understanding rather than contributing to the community by growing the economy or building sustainable communities. It could be argued that to contribute to their community young people first require opportunities to acquire the necessary knowledge and skills. If this was accepted, then Vision 3 would assist young people to contribute to economic and social prosperity for their community and the nation.

The reasons a participant gave for their choice of a preferred vision were important to determine if the vision could accommodate varied approaches for its implementation. The participants were provided with the opportunity to amend the vision to better reflect their opinion if required.

Q2. To implement my preferred vision, it is pivotal ...

To complete this sentence please tick up to three of the statements listed below and provide reason(s) for your choice. In addition to the three selected, a space has been provided for you to construct your own statement if required.

In constructing these pivotal statements attention was paid to the participants' responses to the previous questions related to what was required to implement STEM education.

*Statement 1: the curriculum for STEM education accommodates the development of knowledge and skills within each discipline and across the disciplines of STEM.*

This statement sought to determine if the structure of the curriculum included connections between the STEM disciplines as an integral component of the vision chosen.

*Statement 2: the assessment practices for STEM education focus on the application of knowledge and skills to identify and solve 'real world' problems.*

This statement sought to determine if the application of knowledge and skills in assessing student achievement was inherent in the vision chosen.

*Statement 3: the pedagogical practices used to deliver STEM education inspire young people to choose STEM-related subjects at school and to pursue these into higher and/or further education and careers.*

This statement sought to determine how influential the choice of pedagogy was in the implementation of the vision chosen.

*Statement 4: ongoing high-quality professional learning for teachers is provided that increases their competence and confidence (and experiences) in delivering STEM education.*

This statement sought to determine how important the role of the teacher was in the implementation of the vision chosen.

*Statement 5: implementation of STEM education is co-ordinated to maintain high-quality and consistency across jurisdictions.*

This sought to determine if the vision chosen could be implemented at the national and local level and if sharing locally developed programs and resources nationally was applicable.

*Statement 6: informed communities actively support young people to consider pursuing STEM subjects, careers or employment.*

This sought to determine if the community was an integral component of the vision chosen.

*Statement 7: employment opportunities are available that are attractive to young people who are job capable in STEM and STEM related fields*.

This statement sought to determine if the economic driver for STEM education was inherent to the vision chosen.

*Statement 8: Own statement (not more than 25 words)*

This statement provided participants with the opportunity to provide additional information or clarify specific points related to the vision chosen.

Q 3. Additional comments

This provided the participants with the opportunity to offer additional information or comments.

### 3.3.7 Procedure

The eleven participants who consented to participate in the Delphi study completed and returned all three questionnaires generally by the required return date. The participants were given two weeks to complete and return each of the three questionnaires. The communication with all participants was via email, including reminder emails to return the completed questionnaire which were sent to four participants. Three reminder emails were sent seeking the return of Questionnaire 2 and one reminder email was sent seeking the return of Questionnaire 3. These four questionnaires were subsequently returned. The questionnaires were distributed by email and each questionnaire was emailed separately on the same day to each participant. It took two weeks to analyse the data from Questionnaire 1 and to construct Questionnaire 2. The analysis of the data from Questionnaire 2 and the construction of Questionnaire 3 took three weeks. From the initial email contact seeking consent to participate in this study to the return of the third questionnaire took fourteen weeks.

### 3.3.8 Data Analysis

In this study, there were four steps undertaken to analyse the responses from the participants on each questionnaire. These steps were:

Step 1: the responses to each question on each questionnaire were read and entered in a secure electronic data base. Any response to the questions asked on the three questionnaires

that was thought likely to identify the participant was noted and where possible de-identified as specified in the PLS and Consent to participate in the research.

Step 2: the responses from each participant on Questionnaire 1 were read and any similarities or differences were entered in a secure electronic data base. The analysis of the data was used to construct the second questionnaire and to develop each participant's conceptualisation of STEM education which was later used to investigate why a participant chose a specific vision on the third questionnaire.

Step 3: the rankings for question one and the priorities for question two provided by the participants on Questionnaire 2 were entered in a secure electronic data base. The explanations and additional comments provided by the participants were also recorded and any similarities or differences noted. The analysis of the data was used to construct questionnaire three.

Step 4: the choice of visions and pivotal statements provided by each participant were entered in a secure electronic data base. The explanations and additional comments provided by the participants were analysed for shared opinions or comments, any unique comments or any new ideas presented. This included any responses as to possible amendments to the vision or pivotal statements.

## 3.4 Semi-structured interviews

### 3.4.1 Introduction

Education could be seen as a community of people, where understanding the discourse that occurs between its members is important if innovations and reforms are to be successfully implemented. In this study, the semi-structured interviews were undertaken to build an understanding of the discourse about STEM education in the Australian context and to further explore the participants' responses recorded on the Delphi study and to complement the findings from the document analysis.

In addition, a small group of participants referred to as the Non-Delphi study participants were selected to participate in the semi-structured interviews. Their inclusion in this study was to address the issue of credibility raised by Hasson and Keeney (2011) and others that was discussed earlier in this chapter. The Non-Delphi participants were selected using the same selection criteria as used for the Delphi study participants. The semi-structured interviews with these participants also provided opportunities to further explore the

findings from Delphi study, including the choice of preferred vision for STEM education in the Australian context.

### 3.4.2 Research questions to be addressed by the semi structured interviews

1. What can be learnt from past experiences in education reform that will enhance the implementation of STEM education in the Australian context?
2. What is the likely next step or future opportunities for STEM education in Australia?
3. Which of the three visions developed in the Delphi study was preferred by a small group of participants from the STEM education community?
   What were the reasons given for their choices?

To answer question one and question two, the responses of all participants were analysed. Question three was asked of the Non-Delphi study participants only.

### 3.4.3 Purpose

In this study, the use of the semi-structured interviews provided one source for the collection of data that could be used to compare with that from other sources and so lead to a more credible narrative. The use of semi-structured interviews expanded and further unpacked the findings from the document analysis and the Delphi study. The semi-structured interviews enabled a focus on building the narrative of STEM education in the Australian context. The semi-structured interviews built an understanding of how each participant's conceptualisations of STEM education impacted on their choice of a preferred vision for STEM education in the Australian context and its implementation.

In this study, the first question in the semi-structured interviews conducted asked the participants to describe their experiences and how they thought these were relevant to STEM education in the Australian context and their inclusion in this study. The final question provided an opportunity for the participants to reflect on and speculate as to the future of STEM education. These two questions were designed to encourage the participants to discuss the different contexts in which they had worked and how this had influenced their conceptualisation of STEM education in the Australian context.

### 3.4.4 Application of the semi-structured interviews

In this study and drawing from the work of Mishler (1986), Fontana and Frey (1994) and Partington (2001), four assumptions were made when deciding to use semi-structured interviews. The first was the assumption that in inviting the participants to the interview, they had information relevant to the research questions and were willing to share this with the researcher. Fontana and Frey (1994) and Partington (2001: pp.32-35) believed that to ensure high quality data was collected from interviews it was critical that the researcher gained the trust of the interviewees and established rapport with the interviewees. Partington (2001: p.32) further argued that in choosing to undertake semi-structured interviews, the researcher should be cognizant of the possible problems in interviewing techniques and how to prevent these diminishing the quality of the data collected. In this study, the researcher paid attention to the setting for the interview, the format and type of interview, respecting the interviewees' stance and articulating the purpose of the interview. The researcher also took care when establishing rapport with the interviewees not to lose objectivity or distance by becoming a spokesperson for the group of participants being interviewed (Fontana and Frey, 1994: p.361) or when presenting the findings from the analysis of the semi- structured interviews.

The second was the assumption that the researcher, as the interviewer, had framed questions that would facilitate responses that were then analysed to create meaning from these responses. Partington (2001: pp.32-35) also suggested that the researcher was obliged to explain how the issues were addressed and to discuss the assumptions that related to and underpinned the questions asked in the semi-structured interviews. In this study, the researcher took care when asking the questions to ensure that they did not limit the nature of or direct the responses in a specific direction and that the interviews were transcribed verbatim.

The third was the assumption that use of a mix of general, specific and speculative or future thinking questions would encourage a diversity of responses from the participants being interviewed. Mishler (1986: pp.156-158) suggested that conducting an interview was a complex task that required practice in asking questions that required detailed responses and skills in the presentation and analysis of the responses from the interviewees. In this study, assumptions related to the content and structuring of the questions were explained in 3.4.6, the organisation of the interviews in 3.4.7, and the analysis and presentation of the responses later in 3.4.4.

The fourth was the assumption that the use of appropriate examples to clarify the factors would assist to add depth and richness to the data collected. This was also related to the mix of questions asked as identified in the third assumption. In this study, the researcher explained the relevance of the quotes from the interviews cited to the study to maintain the quality of the analysis of the data (Mishler, 1986: pp.156-158) and Partington, 2001: pp.32-35).

In this study and drawing from the work of Rabionet (2011: pp.563-565) and Partington (2001: pp.32-35), a set of protocols for conducting the semi-structured interviews and the analysis and presentation of the responses from the participants was developed and implemented. The protocols related to the ethical conduct of the study, the anonymity of the participants and the interview settings. The use of semi-structured interviews as being applicable and appropriate to this study was included in the application to conduct this study that was approved by the Office of Research and Integrity of The University of Melbourne (December 2017). The skills and experience the researcher gained as an education bureaucrat was provided as evidence of her ability to maintain ethical guidelines and confidentiality, for example, maintaining confidentially and anonymity of the participants and the secure storage of all data.

In this study, the anonymity of the participants was maintained through the deletion of any specific information from the interview transcripts that would identify the participant. For example, if in response to the first question, a participant named or referred directly to their current employment or position, or to a publication they had authored, any such statements were deleted from the transcript. The interview transcripts were also returned to participants to review for accuracy and to provide permission to use specific quotes or information as stated in the PLS and Consent to participate in the study. All quotes used were de-identified.

In this study, each interviewee selected the date and time, the mode as either face to face or by phone and the venue as either the participant's workplace or the University of Melbourne for their interview. A list of the questions that would be asked in each interview was provided to each participant at least three days prior to the scheduled interview. This approach was taken to establish trust and rapport between the participants and the researcher.

In this study, attention was paid to addressing the eight *Qualitative Touchstones* that Trainor (2013: pp.127-134) believed would assist to maintain the quality and trustworthiness

of the findings made from the analysis of data collected from semi-structured interviews. These touchstones included the use of the literature review and the document analysis to develop the selection criteria for participants in this study, the construction of suitable questions that would generate a breadth and depth of responses related to the study and the provision of the information participants were likely to require. Also included was connecting the interview questions to all aspects of the study as included in the PLS and Consent to participate in this study, the declaration of the researcher's stance to explain how their experiences may impact on the analysis of interview transcript and the integration and interpretation quotes from the participants to provide an understanding of STEM education in the Australian context.

In this study, to maintain the quality of the analysis of the transcripts of the semi-structured interviews, use was made of the six phases of the thematic analysis of the transcripts of interviews presented by Mann (2016: pp.196-254). The first three of these phases, *Familiarisation with the data, Coding* and *Searching for themes* (2016: p.212) were used in the initial analysis of the participants' responses. Evidence of the themes that emerged from the literature review, the document analysis and the findings from the Delphi study was sought in this analysis. The subsequent analysis yielded further important ideas and possible complementary and alternative themes and were examples of *Reviewing themes* and *Defining and naming themes*. (2016: p.213). This study was primarily interested in what was said, not how often it was said across the interviews where the de-identified quotes selected for inclusion in this study were representative of all themes that were evident in the responses from the participants. This was an example of *Writing up* (2016: p.214).

The participants' perspective of the study they were part of and what its outcome may be were recorded and opportunities provided to the participants to provide feedback on the study in the semi-structured interviews. This was done to clarify the researcher's thinking, challenge their analysis of the participants' responses and to support the researcher to revisit the interview transcripts multiple times. An example was in the researcher's later reflections on their stance to understand how their conceptualisation of STEM education may have impacted on the analysis of the data. Another example was in revisiting the transcripts to clarify the themes identified and to explore if there were any inherent assumptions about STEM education that may have influenced the selection of the quotes included in this study.

In addition, the selected quotes were presented as evidence supporting the interpretation and analysis of the data to maintain the quality of the narrative as discussed by Pinnegar and

Daynes (2007). The quotes included were also representative of similarities and differences in responses and included any unique or distinct responses that were supportive or critical of STEM education. This use of direct quotes also provided examples of the types of events described by Webster and Mertova (2007: p.79) and by Daiute (2014: pp.196-254).

### 3.4.5 Selection of participants

There were sixteen participants who were interviewed. Ten participants had completed the Delphi study. Six participants who had not undertaken the Delphi study were also interviewed to provide trustworthiness to the study as suggested by Hasson and Keeney (2011: pp.1695-1704). These participants were referred to as Non-Delphi study participants.

#### *3.4.5.1 Selection of Non-Delphi study participants*

The six referred to as Non-Delphi study participants were selected using the same selection criteria as those used to select the Delphi study participants. The profile for each of the Non-Delphi study participants is presented in Table 3.5.

**Table 3.5 Profile of the Non-Delphi study participants in response to the selection criteria***

| Selection criteria/Participant | M | R | S | T | X | Y |
|---|---|---|---|---|---|---|
| 1. Discipline at least one of S, T, E, M | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2. Published researcher | | ✓ | | ✓ | ✓ | ✓ |
| 3. Published author (book/chapter/editor) | | ✓ | | ✓ | ✓ | ✓ |
| 4. Educator in discipline | ✓ | ✓ | | ✓ | ✓ | ✓ |
| 5. Statutory Authority | | ✓ | | | ✓ | |
| 6. Business | | | ✓ | | | ✓ |
| 7.Leadership - faculty/department/organisation | | | | | ✓ | ✓ |
| 8. Leadership – program | | ✓ | | ✓ | | |
| 9. Leadership- other | ✓ | | ✓ | | | |
| 10. Policy developer/writer | | ✓ | ✓ | | ✓ | ✓ |
| 11. Pedagogy | ✓ | ✓ | | | | |
| 12. Access and equity- gender | | ✓ | | | | ✓ |
| 13. Access and equity- indigenous | | ✓ | | | | ✓ |
| 14. Access and equity- rural/regional | | ✓ | | | | ✓ |
| 15. Assessment | ✓ | ✓ | | | | ✓ |
| 16. Curriculum | ✓ | ✓ | | | ✓ | ✓ |
| 17. Resources development/publications | ✓ | | | | ✓ | ✓ |
| 18. Professional development for pre and post service educators | ✓ | ✓ | | | ✓ | ✓ |
| 19. Educator in STEM | ✓ | ✓ | | | | ✓ |
| 20. Other (philanthropic organisation, research centre) | | | | | | ✓ |
| 21. Media contributor | | | | | | ✓ |

*four of the six participants were female

*3.4.5.2 Examples of the profile of participants and their match with the selection criteria.*

Example 1

Imagine a participant who as an academic led research related to trends in the participation rates of students in senior secondary science subjects and factors that affect subject choices, who is a teacher educator in both pre and post service programs and with numerous publications in journals and chapter contributions to books and has completed reports for governments. This participant would then address criteria 1, 2, 3, 4, 5, 8, 10, 11, 12, 13, 14, 16, 18, 19.

Example 2

Imagine a participant with a long career in research and leadership of international research teams in one of the STEM disciplines with numerous publications in international discipline specific journals, who has presented keynotes at national and international conferences and who has supervised post graduate research students. This participant would then address criteria 1, 2, 4, 8, 20.

### 3.4.6 The Instrument

Each participant was asked between seven and nine questions in their semi-structured interview. There were three questions asked of all participants which addressed their participation in the study, their future advice for STEM education and any other comments they wished to make. Each participant was asked at least one question that was specific to their own experiences. All Delphi study participants were asked two questions related to their participation in the Delphi study. The Non-Delphi study participants were each asked four questions that were not asked of the Delphi study participants. The list of the questions asked of each Delphi study participant is included in Appendix 3. The list of questions asked of each Non-Delphi study participant is included in Appendix 4.

*3.4.6.1 Questions asked of **all** participants*

The three questions that were asked of all participants are discussed below.

*How would you like to be described as a participant in this research? (in 25 words or less).*

This question sought to understand each participant's stance in this study as related to STEM education.

*From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?*

This question encouraged participants to reflect on current and past reforms in education and to suggest possibilities for the future.

*Any other comments*

This question provided the opportunity for each participant to further contribute to building and understanding of STEM education in the Australian context.

*3.4.6.2 Questions **specific** to the **Delphi study** participants.*

*Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.*

*Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.*

These questions related to their participation in the Delphi study and sought to identify if there were other aspects of STEM education in the Australian context that should be investigated.

In addition, each Delphi study participant was asked at least one question that sought clarification of their responses from the Delphi study and that were related to their areas of expertise.

*3.4.6.3 Questions for **specific** to the **Non-Delphi** study participants*

The four questions asked of the Non-Delphi study participants are discussed below.

*Why do you think 'STEM education' is gaining so much attention now?*

This question sought to determine the conditions that led to the introduction of STEM education and related to the questions asked on the first and second questionnaires from the Delphi study. Asking this question of the Non-Delphi study participants was designed to determine if their responses were the same or similar or different to those of the Delphi study participants.

*Which of these visions is your preferred vision for STEM education in the Australian context? Please elaborate.*

This question sought to determine if the choice and the reasons for the choice of the preferred vision were the same or similar or different to those of the Delphi study participants.

*Will STEM education be around 5 or 10 years? Why? If not, what will have replaced it?*

This question sought to investigate the implementation of STEM education and its sustainability and future.

*If STEM education is (or is to be) the answer, what is the question? If it is not the answer then what should question should be?*

This question sought to determine if there were any other questions or areas that should have been explored in this study and possible areas for future research.

### 3.4.7 Procedure

The sixteen interviews, ten with participants from the Delphi study and the six Non-Delphi study participants were conducted over a period of eight weeks and followed the completion of the analysis of all the data collected from the Delphi study. Due to unforeseen circumstances, one participant from the Delphi study, Participant K, was unable to complete the semi-structured interview. Twelve interviews were conducted face to face and four interviews were conducted by phone. A week before the interview, each participant was emailed a copy of the questions that they would be asked. A copy of the interview questions asked of each Delphi study participant is included in Appendix 3. A copy of the interview questions asked of each Non-Delphi study participant is included in Appendix 4. In addition, the six Non-Delphi study participants also received an attachment that listed the three visions developed from the Delphi study to assist them with their response to the question related to the choice of a preferred vision for STEM education in the Australian context. A copy of the attachment is included in Appendix 5.

A pilot study using some of the proposed interview questions was conducted with some of the researcher's colleagues from STEM and non-STEM backgrounds at the Melbourne Graduate School of Education from the University of Melbourne. The feedback provided from this pilot study was used to improve the clarity of the questions to be asked in the semi-

structured interviews. This was done to establish and maintain trustworthiness of the data collected and analysed and of the findings.

### 3.4.8 Data Analysis

To complete the analysis of the responses to the questions asked in the semi-structured interviews, the following five steps were undertaken:

Step 1: each interview took between forty-five and sixty minutes, providing approximately fifteen hours of data from across the sixteen interviews. Each interview was listened to by the researcher prior to being transcribed. The transcriptions of the interviews produced approximately two hundred and fifty pages of data to be analysed.

Step 2: each transcript was first read to detect any responses that would identify the participant. When detected, these were noted and de-identified as stated in the PLS and Consent to participate in the research.

Step 3: each transcript was then re-read carefully to identify key statements and explanations included that were related to the themes that emerged from the literature review and the document analysis and to the findings from the Delphi study. Any new themes identified were noted. Any references pertinent to the curriculum development framework were also noted.

Step 4: responses from each transcript that illustrated similarities and differences between the participants or with other data collected and analysed in this study or were unique were identified and recorded. Specific quotes for possible inclusion in this study were highlighted.

Step 5: the transcript of each participant's interview with any quotes that the researcher wished to cite were highlighted in the interview transcripts. In accordance with the PLS and Consent to participate in this study, the transcript was then returned by email to the participant to review and amend as necessary and to provide written permission to publish the highlighted quotes and then returned to the researcher. A note was made of each quote that was approved to be included in this study.

## 3.5 Conclusion

In this study, the Delphi study was used as one source of data which when combined with data from the document analysis and the semi-structured interviews was used to detail

the introduction and implementation of STEM education in the Australian context. From the findings of the analysis of the data, the challenges facing STEM education in the Australian context were identified. The data for this study were collected over eighteen months beginning with the document analysis, followed by the Delphi study and concluded with the semi-structured interviews.

The document analysis identified the themes in the selected international and Australian documents and allowed a comparison with those that emerged from the literature review. The Delphi study was used to explore whether these themes were also evident in the participants' responses on each of the three questionnaires completed. The Delphi study also identified three possible visions for STEM education in the Australian context. The responses provided by the participants in the Delphi study were further explored in the semi-structured interviews. The interviews with the Non-Delphi study participants provided another source of data to determine if a preferred vision for STEM education in the Australian context could be constructed. The responses from the semi-structured interviews from both the Delphi study and Non-Delphi study participants provided an understanding of how the participants' conceptualisations of STEM education would likely impact on its implementation and future sustainability in the Australian context. It also grounded the study in the present whilst looking towards possible challenges for the future by referencing the success or otherwise of past initiatives and reforms to education.

The narrative inquiry approach was used to present the findings from the document analysis, the Delphi study and the semi-structured interviews that may be of interest to others or assist to shape the ideas and opinions that may inform policy development.

The findings from the analysis of the data from each method used in this study is presented and discussed in the following three chapters as follows: chapter 4 Findings from the Document analysis, chapter 5 Findings from the Delphi study and chapter 6 Findings from the semi-structured interviews.

# Chapter 4: Findings from the Document analysis

This chapter presents and discusses the findings from the detailed analysis of the documents selected from the published authority. This included the identification of the main themes that were shared between the documents or were unique to a particular document or published authority. The themes were then compared with those from the literature review and the links to the phases of the curriculum development framework were also investigated.

## 4.1 Findings

The thirty-two documents were selected from the published authority using the categories discussed in the previous chapter. The number of documents analysed from each group included in the published authority is presented in the Table 4.1.

**Table 4.1 Overview of the documents analysed**

| **Published authority** | **Document category (from Table 3.1)** | **Number of documents analysed** |
|---|---|---|
| Government: International | 1, 2, 3 | 5 |
| Government: Australian<br>Commonwealth<br>States/Territories<br>(included statutory authorities) | <br>1, 2, 3<br>1, 2, 3 | <br>7<br>5 |
| Research | 2, 4 | 6 |
| Professional Associations | 4, 5 | 2 |
| Business/Industry | 4, 5 | 4 |
| Philanthropic organisation | 4, 5 | 1 |
| Other (e.g. The World Bank) | 4, 5 | 2 |

The analysis of twelve of the selected documents has been included below. These documents were representative of the categories listed in Table 4.1. (The complete list of the documents analysed is included in Appendix 1.)

### 4.1.1 Documents from International Governments

The document, *STEM 2026 A Vision for Innovation in STEM Education* was published in 2016 by the USA Federal Government Office for Innovation and Improvement. This document was a detailed report of STEM education and followed an earlier report from 2013.

It was an example of a government agency seeking to build upon and extend previous initiatives to deliver intended outcomes by working with stakeholders interested in STEM education. The stakeholders were industry leaders, policy makers, leaders in education with an emphasis on teaching and learning, improving equity and access, and researchers in the STEM disciplines and education.

The document positioned STEM education as a key component of maintaining a workforce with core cognitive knowledge, skills and abilities applicable to STEM jobs. It also identified that there were still disparities in the participation in STEM education amongst different groups within the USA. The document was intended to address the challenges of making STEM education a reality in the USA.

The document identified six key points that the stakeholders believed would lead to the development of a vision for STEM education that was presented as aspirational and achievable and as such would "promote lifelong learning among all youth and in all communities" (2016: p.ii).

The first key point focussed on the engagement of students and communities using the best pedagogical practices and purposely designed resources. The second key point focussed on providing access to intentionally planned activities with the aim of increasing student engagement, access to and participation in STEM activities. STEM education would introduce diverse and complex content, foster curiosity, promote divergent and creative thinking and take a team-based approach to address real-world problems and challenges. The third key point was the inclusion of interdisciplinary approaches with a focus on a curriculum designed to engage and motivate students to help them understand the relevance and importance of STEM in improving their lives and that of others. The fourth key point was the introduction of flexible and inclusive learning spaces with a focus on pedagogy that is diverse, adaptable, engaging and supports equity of access. The fifth key point was the use of innovative assessment with a focus on formative as well as summative tasks that were meaningful and purposeful and used a variety of modes of assessment and maintained accountability of outcomes. The fifth key point was the promotion of the diverse professions and opportunities for employment that STEM offers, again with a focus on equity of access and engagement of students.

The document was intended to provide a roadmap for bureaucrats at the federal, state and local levels and policy writers to develop specific documents to support education

settings in achieving the vision presented for STEM education. It also encouraged partnerships between all stakeholders to develop suitable resources or to provide employment and further study opportunities for students.

The document, *The report of the STEM Review,* was a joint publication by the UK Government Department of Education and the Department of Employment and Learning and was released in 2009. The report was chaired by Dr Hugh Cormican, CEO of a technology company and the review panel included prominent stakeholders from industry and education. The purpose of the review panel was "to examine the issues related to STEM and make recommendations to ensure future success of STEM education within this region" (2009: p.4).

The document also identified four major imperatives (2009: p.11) and presented twenty recommendations each of which aligned with one of these imperatives. This UK report, like the USA report (2016), was an example of government departments responsible for employment and education seeking to understand what may be limiting the delivery of the intended outcomes of STEM education policies and programs and suggestions for possible future directions. With this future focus, the government departments were positioning STEM education as an ongoing component of the education of all young people in the UK. Similarly, in identifying the issues related to STEM, the report was providing the government and its departments with challenges to ensure the sustained success of STEM education.

The panel also decided to expand its remit to include STEM education in universities to ensure: "the entirety of STEM education was reviewed" (2009: p.5) and introduced the use of the word "artery" (2009: p.5) rather than pipeline to view STEM education as it believed it "better conveys a sense of vitality and represents the many dimensions of STEM education" (2009: p.5).

The panel agreed that a STEM qualified workforce was critical in sustaining economic growth and prosperity in the UK now and into the future. The report positioned STEM education as an essential component of education at all levels. The variation in the focus on equity of access to qualifications in STEM across the policy agenda arena throughout the UK was noticeable and of concern to the panel. This led the panel to recommend that a more cohesive approach to STEM education was required. The promotion of STEM education through planned and cohesive leadership that focussed on the achievement of specified outcomes was regarded by the panel as highly important. To address the disparity in

performance in STEM subjects amongst schools, the panel recommended a focus on equity and access and a curriculum, pedagogy and assessment that were relevant to all students. The panel noted that an increased flexibility in the provision of STEM education would require a focus on pedagogy that accommodated multiple approaches and developed teachers' knowledge, understanding and skills. The report, in response to the panel's belief that a clear vision for STEM education was required included the following vision "Empowering future generations through science, technology, engineering and mathematics to grow a dynamic, innovative economy" (2009: p.11).

The panel believed that the challenge for all stakeholders with an interest in STEM education would be to work collaboratively to achieve such a vision for STEM education. The vision maintains the focus on future economic growth whilst encouraging young people to be innovators. Its purpose was providing a direction for policy writers, educators, business and industry and professional associations involved in STEM education. The report also led to the establishment of the National STEM Learning Centre in the UK.

The documents from the USA and the UK both argued that governments should develop a clear and coherent vision for STEM education to ensure its successful implementation. The documents highlighted the important contribution of STEM education to continuing economic prosperity for their citizens. The documents also presented STEM education as an important economic, political and social issue.

### 4.1.2 Documents from Australian Governments

The document, *Science, Technology, Engineering and Mathematics in the National Interest: A Strategic Approach,* was published in 2013 by The Office of the Chief Scientist Australia. The author of the document was Dr. Ian Chubb, a neuroscientist and academic who held the position of the Commonwealth of Australia Chief Scientist from May 2011 until January 2016 and is credited with the introduction of STEM and STEM education to Australia.

The chief scientist, Dr. Ian Chubb suggested that "*to achieve a Better Australia"* (2013a: p.4), a social compact was required that included all Australians. This social compact was designed to draw together education, knowledge, innovation and influence from the disciplines of science, mathematics, engineering and technology and led to the introduction of STEM education in Australia. This document positioned STEM education as an important component of building a better Australia for all Australians.

Dr. Ian Chubb believed that two key points provided the focus for the development and implementation of appropriate strategies that would lead to a better Australia. First was the use of contexts to build knowledge and skills through enhanced practices in curriculum, pedagogy and assessment that would develop an ongoing supply of research specialists and technicians and an informed community. Chubb also argued that access and equity of access for all Australians to STEM education was essential for them to develop the twenty-first century skills necessary for future careers and employment. Second was building social cohesion and economic prosperity so that all Australians had confidence in the "moral and ethical behaviours of STEM practitioners to provide solutions to challenges" (2013: p.11).

This document positioned the implementation of STEM as critical to Australia's future prosperity. Dr. Ian Chubb challenged all interested stakeholders to become involved in debates about how best to develop and implement STEM education programs in schools.

In response to the paper from Chubb (2013a), the Education Council of Australia (ECA) (consisting of the Ministers of Education from the Commonwealth and the state and territory governments) published in 2015 the *National STEM School Education Strategy. A comprehensive plan for Science, Technology, Engineering and Mathematics Education in Australia. 2016-2026.*

The document included a detailed plan for STEM education in Australia. Like the more general STEM strategy provided by Chubb (2013a), the National STEM School Education Strategy (ECA, 2015) sought to position STEM education as being aspirational:

> a renewed national focus on STEM in School Education is critical to ensuring that all young Australians are equipped with the necessary STEM skills and knowledge that they will need to succeed. (2015: p.3)

and purposeful:

> to build on a range of reforms and activities already underway. It aims to better coordinate and target this effort and sharpen the focus on the key areas where collaborative action will deliver improvements to STEM education. (2015: p.6)

This led to the development of two goals for STEM education in Australian schools. The first goal was to: "ensure all students finish school with strong foundational knowledge in STEM and related skills" (2015: p.5) and focussed on access and equity and the acquisition of specific knowledge and skills. The second goal was to: "ensure that students

are inspired to take on more challenging STEM subjects" (2015: p.5) and focussed on student engagement, the content of curriculum and pedagogical and assessment practices.

The document included two national areas for action. At the school level STEM education is delivered by bringing together schools, teachers and students in partnership with universities, business and industry and at the national level by building a strong evidence base to identify successes in implementation of the strategy and to better understand what is effective and works best in the Australian context. This was seen as pivotal to tracking trends at the national level over time to ensure the goals were being met. To implement the goals and address the areas of actions, all stakeholders were encouraged to work collaboratively to provide excellence in STEM education within local and national contexts and to evaluate and report student outcomes. This document also led to the development of STEM education policies and programs by the individual Australian state and territory governments.

An example of a state government document is *VicSTEM (Science, Technology, Engineering and Mathematics): STEM in the Education State* published by the Department of Education and Training Victoria in 2016. The inclusion of STEM education in Victorian schools was endorsed by the Victorian Government, with responsibility for its implementation resting with the Department of Education. *VicSTEM* (2016) was reflective of the National STEM School Education Strategy (ECA, 2015) and was designed to be implemented within the context of education in Victoria. It provided a plan of the actions required to deliver the vision for improved learning and outcomes in STEM from early years to senior secondary years and in higher education. The government expected these improved outcomes to lead more Victorians to employment and careers in STEM related fields. The government also believed that the inclusion of STEM education would enhance Victoria's position as the *education state* of Australia and continue its social and economic prosperity and growth. To achieve the intended outcomes of this strategy, STEM education would need to actively involve students, families and partnerships between schools, communities, business and industry in planning education programs. Other Australian states and territories including New South Wales and Queensland have produced similar documents to support their schools to implement the agreed national strategy for STEM education.

The government documents from Australia focussed on the importance of the provision of STEM knowledge and skills for all students and the implementation of programs that would increase the participation of students in STEM related subjects. This was seen as necessary to grow economic and social prosperity by positioning STEM education as a

necessary component of the education available to all young Australians so that they can contribute to the nation's future prosperity.

### 4.1.3 Document from an education research organisation

The document, *From concept to classroom Translating STEM research into practice* authored by Christine Rosicka, was published by the Australian Council for Educational Research (ACER) in 2016. ACER is an independent, not-for-profit research organisation. Its mission is to create and promote research-based knowledge, products and services that can be used to improve learning across the life span (ACER, 2019).

Rosicka (2016) investigated the implementation of STEM programs in primary schools. She found that sustained professional learning was required to support the integration of STEM learning areas. Rosicka (2016) also found that the application of a shared and coherent definition of STEM education supported the development and the implementation of programs designed to increase engagement and participation and access in the STEM learning areas. Rosicka recommended that further research be undertaken into the impact on student outcomes of integrated STEM education programs. Rosicka (2016) argued that this research should focus on curriculum content and pedagogical and assessment practices. Rosicka also encouraged the use of education research to help teachers identify STEM education programs that could be implemented in their classrooms and would assist them to focus on the accountability of student outcomes or achievement standards.

Rosicka also commented that good practice in primary STEM education programs looks very similar to good practice in primary education in general. Rosicka (2016) further believed that the challenge for STEM education in Australia was to apply these same principles within the context of STEM specific content, knowledge and skills. Rosicka's research positioned STEM education as a vehicle to review, renew and innovate practices in curriculum development, pedagogy and assessment.

### 4.1.4 Document from a business

The document*: Practical steps to improve the quality of science and mathematics teaching in primary schools. Making STEM a primary priority,* was published by PricewaterhouseCoopers (PwC) Australia in 2016. PwC Australia is part of a large international organisation with interests in futures planning, thinking and forecasting "gaps in

response to trade pressures: decisions around data adequacy and analysis; talent, workforce and skill gaps" (2016: p.2).

In this report, PwC positioned STEM education as being fundamental for continuing Australia's prosperity through the provision of a "STEM capable workforce" (2016: p.5) and pointed to what it labelled as the "systemic under-achievement in STEM education" (2016: p.6) and presented the report as "signpost steps" (2016: p.6) to ensure "every child finishes primary school with fundamental STEM knowledge and skills" (2016: p.7).

The report identified four areas for action. First was building teachers' knowledge and understanding of STEM to enhance student engagement and achievement in science and mathematics and to produce specialist STEM teachers and informed generalists for all primary schools. Second was an improved standard of professional development in primary science and mathematics for all teachers with a focus on building teachers' capacity to adopt and apply appropriate pedagogies that will increase student achievement in science and mathematics and STEM activities. Third was increasing the quality and quantity of STEM instruction in Australian primary schools with a focus on best practice in curriculum, pedagogy and assessment. Fourth was improving assessment through the collection and interrogation of student achievement data and ongoing monitoring and evaluation of programs which included accountability for the quality of the teaching and learning students received.

The report acknowledged that both time and funding were required to implement these four actions. This would include funding every Australian primary school regardless of location to have access to a specialist STEM teacher rather than expecting all teachers to be trained in STEM and fostering collaborations between schools and other partners interested in driving STEM education (2016: p.6). The recommendations from this report were similar to those included in the Queensland and Victorian government documents, some of which the governments have implemented.

It is interesting to note that the report used a deficit model approach to STEM as evidenced by the use of phrases such as "the vicious cycle of STEM underachievement" (2016: p.12) and "we are presently trapped in a cycle of educational complacency" (2016: p.12).

Perhaps the most important message from this report is found in its conclusion where the result of ignoring STEM education is starkly articulated but countered with optimism.

> Either we prepare the next generation to thrive in an increasingly technologically complex and competitive global economy or we acquiesce to lower productivity, slower growth and declining standards of living. The task of equipping the future workforce with the STEM skills, knowledge and curiosity required to prosper in an era of technological disruption begins in primary school. (2016: p.12)

and

> Likewise, the implementation challenges are surmountable, provided key stakeholders accept that the interests of students are paramount and that goodwill can be established across different educational sectors and different levels of government. To do otherwise endangers Australia's future prosperity and relinquishes our chance to lead the STEM innovation of the future. (2016: p.12)

This report referenced students in terms of their future contributions to growing the nation's economy and positioned STEM education as leading to the supply of a suitably trained workforce. This report, similar to Rosicka (2016), also recognised the importance of high-quality professional development for teachers in implementing STEM education.

#### 4.1.5 Document from a professional association representing one of the STEM disciplines

The document: *Engineers Make Things Happen. The need for an engineering pipeline strategy summary report* was published by Engineers Australia in 2017. Engineers Australia (EA) is a professional body that advocates for the profession and has responsibility for the registration of engineers and the provision of accredited professional development for their members. EA was also interested in supporting STEM education:

> We admire the dedication and foresight of educators who help students of all ages explore STEM subjects. By instilling a passion for the invaluable components of an engineering mindset in children at a young age, you ensure Australia's future needs are met with rising talent. (2017: p.2)

This report positioned STEM education as a possible way to address the supply of engineers that was required to support continuing economic growth and global competitiveness for Australia. To ensure there were sufficient engineers, the report identified three actions that were reflective of Chubb's social compact (2013a) and the two goals from the National STEM School Education Strategy (ECA, 2015). First was to address the decreasing student participation in STEM subjects of physical sciences, and intermediate, advanced or specialist mathematics. The report suggested a focus on increasing the

engagement and access of students particularly girls, to STEM knowledge and skills and the opportunities for future careers in STEM and STEM related fields. Second was to create a gender balanced profession by increasing the number of women in the profession through improved equity of access to tertiary courses and employment related to engineering. Third was establishing and supporting programs at local levels to address the deficit in STEM knowledge and skills demonstrated by teachers, students and parents and the general community through the co-delivery of education programs by engineers and teachers in schools. The report suggested that access to continuing professional development for teachers and school leaders was also required.

The report provided policies and recommendations in the areas of school education, workforce development and skilled migration which were all designed to ensure a sufficient supply of highly qualified and innovative engineers. In so doing, the report challenged all stakeholders to find solutions to the issues of providing greater access to STEM education programs that engage all students and are delivered effectively through high-quality teaching to ensure "if Australia is to become an innovative nation, our engineering capacity must expand … and a looming crisis in STEM in Australia is to be avoided then action is required now" (2019: p. 70).

It could be argued that the report, by focussing on the decline in participation in STEM subjects at senior secondary school and tertiary levels and the gender imbalance in the engineering profession presented a deficit approach to STEM education similar to that of PwC. EA, like PwC, was optimistic that if the suggested actions were implemented, then the provision of the high-quality STEM skilled workforce required for Australia's future economic growth was possible.

#### 4.1.6 Document from a philanthropic organisation

The Invergowrie Foundation is a public charitable trust established in 1992 to advance the education of girls and women within Victoria. It commissioned the report *Girls' Future – Our Future'* (Hobbs et al., 2017). In particular, the Foundation was concerned with the participation of girls and women in STEM education and argued "that girls and STEM (Science, Technology, Engineering and Maths) was a high priority" (2017: p3).

The report found that future economic growth would be enhanced by increasing the retention of girls and women in STEM related subjects and careers. The development and the inclusion of STEM education programs in the early and junior years of primary school

education was identified in the report as being essential in addressing the future social and economic prosperity of girls and women. The report suggested that achieving this would require a coordinated approach to curriculum and pedagogy to engage all students and in particular girls, building teacher confidence and competence in teaching STEM, and fostering the establishment and sustainability of strategic partnerships between schools, industries, universities and local communities.

The report positioned STEM education as improving the access and equity of access for girls and women to future prosperity by broadening their options and career pathways. The report also strongly emphasised the importance of including all members of the community to deliver better outcomes for girls, which was consistent with actions included in documents from governments and professional associations.

#### 4.1.7 Document for a national curriculum that included STEM education

The Australian Curriculum Assessment and Reporting Authority (ACARA) was created in response to the *Melbourne Declaration of Educational Goals for Young Australians* (2008). ACARA was responsible for the development and the online publication of the Australian Curriculum (AC) that "sets the expectations for what all young Australians should be taught, regardless of where they live in Australia or their background" (2019).

ACARA operates as an independent statutory authority under the auspices of the Australian Commonwealth and state and territory governments. It was responsible for the inclusion of STEM education in the Australian Curriculum in accordance with the National STEM School Education Strategy (ECA, 2015). This led to an integrated approach which positioned STEM education as strengthening authentic connections between existing learning areas and assessment tasks that provide opportunities for students to create possible solutions to identified problems or issues.

Although the STEM disciplines of Science, Technology and Mathematics were included as separate learning areas in the AC, Engineering was not. The challenge was to include the appropriate engineering content, systems and design principles within the existing structure of the AC. The engineering content would be addressed as STEM knowledge and skills, drawn as appropriate from the existing learning areas of Science, Technologies and Mathematics. Engineering principles and systems would be addressed in the Design and Technologies strand of the Technologies learning area. To support schools and teachers to adopt an integrated approach to STEM education, ACARA developed a number of resources.

These included the STEM portfolio consisting of work samples including examples of student responses to STEM tasks and illustrations of examples of school STEM programs from across Australia. A portal for activities and programs for families and other providers of education to support the community's active participation in STEM education has been developed.

In implementing STEM education, this document favoured an integrated approach to the learning areas and the general capabilities as suggested by English (2017) and Johnson (2013).

### 4.1.8 Documents related to STEM skills

The term, *STEM skills,* has been included in both international and Australian publications related to STEM education. Business and industry were particularly interested in the development of STEM skills that would assist companies to grow and remain competitive in local and global markets. Future employment and career opportunities for young people are often presented by business and industry as being in STEM or STEM related areas. This would require education programs that develop knowledge and skills in STEM. This also positioned the inclusion of specific skills in STEM education as of critical economic and social importance.

The World Bank, an international organisation, commissioned research by Wendy Cunningham and Paula Villaseñor into the skills employers expect their workers to develop and display and as such positioned STEM education as being vital to developing a country's economic and technical expertise. The World Bank is not a bank in the ordinary sense but rather a unique partnership with developing countries to reduce poverty in developing countries through supporting education and employment in new industries (The World Bank, 2019).

The report of the research, *Employer Voices, Employer Demands, and Implications for Public Skills Development Policy Connecting the Labor and Education Sectors* was published in 2016. Although the research was conducted in developing countries, the classification of skills that are labour market-related was relevant and applicable to STEM education.

The report found that the best programs to prepare young people for the labour market consisted of four different types of skills. These were basic cognitive skills, for example fundamental literacy and numeracy, higher-order cognitive skills, for example critical and

creative thinking and problem solving, technical skills specific to particular jobs, and socio-emotional skills, for example working in teams, commitment and honesty. The development of these skills, the report recommended, would require more than on the job training or further education. It suggested that some of these skills should be developed at home and at school, from middle childhood and adolescence and then continue into adulthood. The employers valued socio-emotional and higher-order cognitive skills that were often not included in school education programs, which the report found led to a mismatch between educators and employers. This supported the need for collaborative partnerships to ensure high-quality STEM education programs in other documents from business and industry and reporting on research.

In Australia, similar attempts have been made to define STEM skills. The National Centre for Vocational Education Research (NCVER) is the national professional body responsible for collecting, managing, analysing and communicating research and statistics on the Australian Vocational Education and Training (VET) sector and is owned by the Commonwealth, state and territory ministers responsible for VET. In 2016, the NCVER commissioned researchers Gitta Siekmann and Patrick Korbel to undertake a document review to clarify the definition of STEM skills and how these may be delivered in education and training programs. Their findings were published in *Defining 'STEM' skills: review and synthesis of the literature. Support document 1* (2016).

The key finding from this research positioned STEM skills in the Australian context as consisting of three distinct groups: discipline-related technical, socioemotional and advanced cognitive. Siekmann and Korbel (2016) suggested that the discipline-related and technical skills are included in the Australian Curriculum learning areas of Science, Mathematics and Technologies and in the general capabilities of literacy and numeracy. The socioemotional and advanced cognitive skills are included in the general capabilities of critical and creative thinking, personal and social, intercultural understanding, information and communication and ethical understanding. Siekmann and Korbel further argued that the integration of knowledge and skills in STEM education programs would deliver the required specialists for example, scientists, engineers and technicians as well as generalists, that is, literate citizens capable of making informed decisions about their future.

### 4.2 Discussion

In Australia, as in other developed countries, the political imperative was focussed on responding to the changes in the traditional manufacturing base of the economy brought about through increasing global competitiveness and use of technology. This led to new initiatives such as growing a knowledge and innovation-based economy as suggested in 2000 by the then Australian Trade Minister, Mark Vaile in a speech to business leaders. It is worth noting that the decline of manufacturing in Australia was first documented in the 1985 Commonwealth Government Report of the Committee of Inquiry into the Labour Market Programs.

Themes that emerged from two Australian Government documents (Chubb, 2013a and the National STEM School Education Strategy (ECA, 2015) where the government was the published authority were similar to those from documents published by the governments of the USA and the UK. Each document emphasised the relationship between STEM education, a skilled workforce and continuing national social and economic prosperity. Student engagement through innovative curriculum and pedagogy was also presented as a way to improve access and equity of access for all students, particularly those previously under-represented in STEM related subjects and careers. Governments also expected schools to be accountable for improving student progress and achievement in STEM education.

The Australian Government documents analysed were also concerned with establishing a co-ordinated approach to the implementation of STEM education much like those from the UK Government. Rosicka (2016) focused on the implementation of STEM education in primary schools and also recommended that similar research be undertaken to investigate the implementation of STEM education programs in early childhood settings, secondary schools and university courses. Such research would identify any practices, themes and issues that were common to the early years, primary and secondary education or if these were unique to each sector.

The curriculum documents analysed suggested varied approaches to including STEM education in teaching and learning programs. Whilst an integrated or connected approach between the STEM disciplines was favoured, the resources produced would need to accommodate varied pedagogies and assessment tasks. As illustrated by the Australian Curriculum and *VicSTEM* documents, the approach to curriculum, pedagogy and assessment in STEM education was presented as a cohesive package that engages and is relevant to all

students. The production and publication of appropriate resources to assist school leadership teams and teachers implement STEM education were also seen as necessary.

The documents commissioned by business or industry and professional associations shared concerns about the availability of a future workforce with the necessary STEM knowledge and skills to grow the economy and address the complex problems that will likely arise into the future.

The Invergowrie Foundation, as a philanthropic organisation, was supportive of the development of innovative teaching and learning programs that encouraged and supported increased and active participation by girls and women in STEM education. As a collective, philanthropic organisations focussed on supporting effective programs that included opportunities for sharing successes across schools and fostered continuously improving outcomes for all students.

The documents that focussed on identifying the skills young people would require for employment emphasised the relationship between increasing a nation's economic growth and its access to a suitably skilled STEM workforce. This workforce, from the perspective of employers and governments, required basic and higher order skills that would be developed from home, the family, community, education in schools, universities, vocational training centres and on-site training for specific jobs. Importantly programs designed to assist young people develop these skills would require collaborative partnerships that included representatives from the community, education sectors and employers to prevent what was sometimes seen as a mismatch between the skills employers expected and those young people developed from their education. All young people should have access to these programs.

The documents analysed identified five themes that underpinned STEM education. These were engagement of students, access and equity of access, curriculum, assessment and pedagogy.

The themes were similar to those evident in the literature review. In combination, curriculum, pedagogy and assessment build the required STEM knowledge and transferable STEM skills. Equity of access for all students to STEM education was seen as integral to current and future social cohesion, prosperity and economic growth and addressed the lower participation of girls and women in studying STEM subjects and entering STEM related careers. Increased engagement of students and interest in studying STEM subjects at school and beyond, particularly those that are seen as more being difficult, such as higher-level

mathematics or physics is necessary to facilitate a greater uptake of STEM related employment opportunities. This in turn would support continuing economic growth and social prosperity. The development of assessment practices that supported student learning in STEM related subjects was presented as contributing to increased engagement of students and increasing numbers of students pursuing higher level studies in the STEM disciplines.

The beginning of the twenty-first century provided a new direction for policies with a focus on developing an appropriately skilled workforce. This workforce was described as being flexible and adaptable, and able to respond quickly to new opportunities. It was in this environment that STEM education was introduced in Australia albeit later than in the USA or the UK. Politicians and some business and industry leaders argued that more workers with higher levels of qualifications and skills in science, technology, engineering and mathematics were needed so that people were well placed to take up jobs that had not yet been invented in industries that may not yet exist!

The relationship between STEM education and the curriculum development framework was also investigated in the analysis of the selected documents. The emphasis on the development of STEM skills was evident in the Empiricism phase of curriculum development. It also was related to the Nature of Science phase of curriculum design where both specialist and technical knowledge as well as more generalist knowledge and related skills were included. The provision of learning experiences that were relevant and accessible to all students was an integral component of the Progressivism and Neo-progressivism of phases of curriculum development. Improving student achievement and outcomes in STEM related subjects was evident of the Standards-based reform phase of curriculum development where governments expect accountability for the funding expended on education along with high rankings of student performance on international tests.

The theme of *engagement of students,* including the relevance of content and resources, was a focus of government documents, for example the USA (2016), education researchers with a focus on curriculum, such as, Dewey (1902) and Schwab (1973), and professional associations such as Engineers Australia (2017). This interest in engaging students in and with their education was evident in the Empiricism, Progressivism and Neo-progressivism phases of curriculum development.

The theme of *access and equity of access* included gender, low socioeconomic, regional or rural or remote and indigenous and was a focus of documents authored by governments,

including the USA (2016), education researchers, (Huxley, 1868 and Young, 1971, 2008) and the community (Hobbs et al., 2017, Cunnigham and Villaseñor, 2016). Access and equity of access has been of interest and an influence on policy related to curriculum development and curriculum since the Empiricism phase of curriculum development.

The theme of *curriculum content* included knowledge and skills, breadth versus depth of content and generalist versus specialist learning areas. This was also a focus of education researchers, including Tyler (1949) and Bybee (2013). This interest was related to the issue of engagement of students and was reflective of the political climate that was evident at a particular time, including the Nature of Science phase of curriculum development and debates about an education that produced specialists in particular areas to raise the nation's global status.

The theme of *pedagogy* included diverse approaches to STEM education that depended on the age or year level of students. These approaches included making connections between the separate disciplines or taking an interdisciplinary or multi-disciplinary or integrated approach when delivering activities or programs. Examples of documents where pedagogy was a focus were prepared for the community (Hobbs et al., 2017), education researchers (Rosicka, 2016) and business and industry (EA, 2017, PwC, 2016). Education researchers such as Dewey (1902), Fensham (1986) and Young (1971) were also concerned with pedagogical practices. The interest in pedagogy was influenced by the content and organisation of the curriculum the political and social climate, as evident for example in the Neo-progressivism phase of curriculum development with its emphasis on addressing social inequities.

The theme of assessment, including the type, frequency, use, data collection and analysis were a focus of documents authored by governments (The National STEM School Education Strategy, ECA, 2015). This theme gained in significance and influence with increased accountability of Government expenditure on education through increased student performance against a set of standards as in the Standards-based reform phase of curriculum development.

The document analysis also identified links and references to other documents that were not initially included in the literature review that provided valuable insights that were used to construct the curriculum development framework. In the Australian context, Fensham (1960) and Boomer (1992) identified and discussed the political, economic and social context that

influenced curriculum policy and development in Australia that existed prior to the introduction of STEM education and identified possible future developments in curriculum.

The analysis of the selected documents assisted with the identification of possible participants for the Delphi study and the semi-structured interviews. Some documents that related to implementation of STEM suggested that the inclusion of The Arts in programs would assist with developing students' skills in creativity and design. This has led to the emergence and use in Australia of the acronym, STEAM, where the 'A' represents The Arts.

The interest shown in STEM education by professional associations representing engineers, business groups and philanthropic organisations led to the decision to include participants from these organisations in this study. Similarly, a decision was made to include a participant who was a researcher in education and an advocate of STEAM in Australia and internationally in this study.

### 4.3 Conclusion to the document analysis

There was consistency between the themes that emerged from the analysis of the international and Australian selected documents. The emphasis or importance placed on particular themes in each of the documents analysed was dependent on the author's or commissioning agency's stance and their position and the education jurisdictions and their respective agenda. The documents selected give an indication of the diverse groups who have an interest in STEM education and how their opinions coalesce or differ and the impact this has on policy and implementation decisions.

International and Australian Governments focussed on the political, economic and social benefits of STEM education and accountability for improving student achievement and outcomes. This was also reflected in the published curriculum documents analysed where the content as knowledge and skills specific to STEM education was identified and assessment of student understanding was measured against set standards.

Business and professional associations placed a strong emphasis on the need for action now from governments to build a suitably qualified STEM workforce. They considered such a workforce was necessary to tackle current and future issues related to employment opportunities to ensure continued economic growth and sustained global competitiveness.

Research and philanthropic organisations focussed on access for students to high-quality education including best practices in teaching and learning, assessment and curriculum design.

The strength of the influence of the political or economic or social context operating at the time of publication of the documents was reflected in the language used in the documents and in the intended audience for the documents. There was consistent agreement on the need for the inclusion of STEM education in primary and secondary school programs but there was less consistency in what such programs would look like, with some also commenting on its inclusion in the early years and tertiary education and training.

STEM education was seen as being an important factor in ensuring continuing and future economic prosperity, social cohesion and preparing a nation's citizens to meet and solve future and complex challenges. There was a recognition that this would require the development of knowledge and skills that would provide employment opportunities for all young people. As such, the delivery of high-quality STEM education would require input from all those interested in or responsible for its implementation. This included governments, business and industry, specialists in the STEM disciplines, educators, professional associations, communities, policy writers, curriculum and resource developers, researchers and the media.

The themes that emerged from the document analysis were also consistent with the principles that underpinned the phases of curriculum development as presented in the curriculum development framework. The themes were also a focus for the education researchers and their approaches to curriculum design and student learning. Huxley, from the Empiricism phase, focussed on the inclusion of the development of skills within the curriculum that would enable the students to access employment in new fields as these emerged. In contrast, Dewey, from the Progressivism phase, focussed on the provision of experiences as a combination of curriculum, pedagogy and assessment that were accessible, relevant to and engaged the learner. Tyler, from the Nature of Science phase, supported an outcomes-based approach to curriculum design where all students were given sufficient opportunities to demonstrate growth in understanding and achievement of the outcomes. Schwab, from late Nature of Science phase into Neo-progressivism phase, focussed on developing understanding through inquiry as opposed to memorising a list of facts. Young, working across Neo-progressivism and Standards-based reform phases, argued that knowledge was a social construction. Matching the knowledge from the curriculum to

particular situations and points in time was important for learner engagement. This is an example of the use of *powerful knowledge* (Young, 2007)as an approach to curriculum design. Similarly, Bybee, working across Neo-progressivism and Standards-based reform phases, also supported an inquiry approach as evident in the 5E model he developed (2009). Bybee supported building student engagement through the provision of the highest quality teaching and learning, using contemporary practices in curriculum, pedagogy and assessment.

The analysis of the documents demonstrates that there was a belief that STEM education was important and that it provided opportunities to better engage young people in their education. The relevance of the curriculum development framework to the document analysis is discussed in 7.3 and 7.6. However, exactly what STEM education should look like and how it should be implemented was open to debate and required further research.

The following two chapters will focus on developing an understanding of the challenges for STEM education in the Australian context and how these related to what was happening internationally. Chapter 5 will present the findings from the Delphi study and chapter 6 will present the findings from the semi-structured interviews. Chapter 5 will also examine how the selected participants conceptualised STEM education and their choice of a vision for STEM education in the Australian context.

# Chapter 5: Findings from the Delphi Study

This chapter presents an analysis of the data collected from the three questionnaires of the Delphi study. This enabled a further investigation of how STEM education is conceptualised and a consideration of whether it was possible to construct a preferred vision for STEM education in the Australian context. The findings from the analysis of the data are discussed, including the identification of possible implications for STEM education and its implementation in the Australian context.

An explanation of the construction of the three questionnaires is included in the 3.3.6.1, 3.3.6.2 and 3.3.6.3 respectively.

## 5.1 Findings from Questionnaire 1

The first questionnaire using open-ended questions gave the eleven participants the freedom to express their opinions and ideas. This was consistent with the Delphi approach of using an initial questionnaire to seek and capture the opinions of the participants relating to a particular issue which, in this study, was STEM education.

### 5.1.1 Question 1

*What do you believe is the purpose(s) of STEM education?*

When analysing participant responses to this question for evidence of the themes identified in the document analysis the following decisions were made. First, evidence of *engagement of students* included increasing student interest, promoting student interest, increasing or enhancing student interaction and dialogue with STEM related activities both in and out of school. Second, evidence of *access* included the provision of opportunities in STEM education for all students within traditional and non-traditional education settings in metropolitan, regional, rural and remote areas. Also included was increasing the numbers of students in STEM subjects generally and specifically from under-represented groups for example girls and indigenous communities. Third, evidence of *curriculum* included both curriculum in general and curriculum for specific settings, for example Early Years (EY) or primary and secondary schools or Higher and Further Education. Fourth evidence of *pedagogy* included teaching and learning programs, units of work and programs outside schools, for example at museums, libraries and science centres. Fifth evidence of *assessment*

included project-based work, investigations in a group or individually and terms such as authentic, personal or purposeful and oral or multimedia presentations.

In responding to question 1 the participants listed multiple purposes for STEM education. The analysis of these responses identified five qualitatively distinct purposes for STEM education as shown in the table below.

**Table 5.1. Purposes of STEM education**

| **Purpose of STEM education** | **Participants who included the purpose** |
|---|---|
| a. Economic including workforce, employment, global, increased participation in STEM subjects | B, C, D E (referenced STEM hobbies), F, K, L, P |
| b. Student engagement to build understanding knowledge and skills, relevance (solve real-world problems, approaches) | A, C (as transferrable 21st Century skills), D, G |
| c. Social including participation in community (sustainable, ethical) | D, E, H |
| d. Future uncertainty/changing/complex | C, E, F, G |
| e. Discipline knowledge | E, G, K, H (inclusion of other disciplines), P |

There were also three responses to this question that were initially considered to be outliers as these had not been mentioned by any other participant. However, further analysis of these determined that these responses would align with at least one of the purposes listed in Table 5.1 as discussed below.

Participant E included "*to create new knowledge".* If discipline knowledge was seen as including the fostering of research that led to advancements in understanding and new knowledge, then this response would align with and was included in purpose e. in Table 5.1.

Participant F included for "*information-rich modern economy".* If the response was seen as relating only to the economy, then it would align with and was included with purpose a in Table 5.1. If this response was seen as using the term 'modern' to describe the now and the future, then it would also align with and was therefore included in purpose d. in Table 5.1.

Participant P included "*pathways for the next generation of specialists".* If the response was seen as relating to the supply of highly qualified people to grow STEM related research

and knowledge and the STEM economy, then it would align with and was therefore included in purposes a and b in Table 5.1. In their response to this question, the participant had already referenced economics as a driver of STEM education.

The most supported purpose with eight participants was Purpose a: *Economic including workforce, employment, global, increased participation in STEM subjects.* This suggested a general acceptance by the participants that STEM education would contribute to Australia's continuing economic and social prosperity. This could be seen as providing an endorsement of policy, for example The National STEM School Education Strategy (ECA, 2015) and was reflective of the arguments presented by Blackley and Howell (2015).

The next most supported purpose with five participants was Purpose d: *Discipline knowledge.* This suggested that STEM education is about more than a set of skills and that it should include building knowledge and understanding of the respective STEM disciplines. This was consistent with the approach undertaken to include STEM education in the Australian Curriculum.

Less supported was Purpose b: *Student engagement to build understanding knowledge and skills, relevance to solve real-world problems* and Purpose e: *Future uncertainty/changing/complex,* with each purpose attracting four participants. This was surprising given that increased or enhanced student engagement through the use of activities relevant to them and their futures was one of the themes identified from the document analysis. Similarly, given the emphasis placed on increasing the participation of students in STEM related subjects and careers in policies, for example Chubb (2013) and Engineers Australia (2017), the lower level of support for these purposes was also unexpected. However, the level of support suggested that some consideration should be given to the possible role of STEM education in better engaging students in and connecting them to investigating and solving problems relevant to them now or for their futures.

The least supported purpose with only three participants was Purpose c: *Social including participation in community (sustainable, ethical)*. This suggested that these participants believed that STEM education together with the inclusion of other disciplines or learning areas would offer all young Australians an education that addressed the issues such as sustainability that would likely impact on their futures.

Rather than listing some specific or discrete purposes, three participants grouped together particular aspects of the political, economic or social context for STEM education.

For example, Participant P combined innovative curriculum, access in all education settings, and assessment for all students from EY to Year 12. Participant P also referenced accountability in the use of "clear evidence-based support materials and assessment". The inclusion of innovation reflected the links between different Australian government policies such as the National Science and Innovation Agenda (ARC, 2015) and the National STEM School Education Strategy (ECA, 2015).

Participant B also combined the economic driver of STEM education with curriculum content and governments' political agendas of providing greater student access to STEM education and was "economic driven, employable skills, … broader demographic of students in STEM tertiary subjects".

In responding to this question, Participant D took a different approach when compared to that of the other participants. This participant identified three distinct perspectives for STEM education each of which had a particular purpose depending on the context, for example government or educators or education researchers. Participant D suggested that governments were focussed on growing the economy, educators focussed on increasing student engagement and some education researchers were focussed on curriculum and pedagogy related to developing a particular skill set. In this response, Participant D directed attention to how STEM education is conceptualised and understood by different groups, including "politicians, global economic conditions, secondary teachers: meaningful engagement; ethically-minded educators: education for sustainable development using transdisciplinary skills."

### 5.1.2 Question 2

*Given the purpose(s) of STEM education you identified in question 1 what is necessary/required to achieve/implement this purpose(s)?*

The initial analysis of the requirements listed by the participants identified eight different requirements as shown in Table 5.2. Within the requirement of curriculum, four sub-themes emerged and these are also shown in Table 5.2.

**Table 5.2 Requirements for implementation of the purposes of STEM education**

| **Requirements for STEM education** | **Participants who included the requirement** |
|---|---|
| a. Shift from content knowledge to process skills | B |
| b. Problem solving tasks and projects draw on disciplines with real life or relevancy or social purpose (draw on other disciplines) | A, F, G, K |
| c. High-quality continuous professional development/learning (post and pre-service) | C, E, H, K, L |
| d. Curriculum included<br>• supportive integrated approaches<br>• foundational studies in science and mathematics<br>• interdisciplinarity (integration of learning areas to transdisciplinary and disciplinary knowledge and skills)<br>• innovative EY-12 curriculum | <br>C<br>F, G<br><br>A, D, L<br>P |
| e. Teachers working in teams | A, G |
| f. Investigations that apply knowledge and skills and approaches | G |
| g. Input from organisations and partnerships | E, H |
| h. High-quality and innovative resources | K, P |
| i. Authentic teaching, learning (and assessment) draws across the STEM subjects | L |

Participant B, in selecting requirement c, commented on the need for teachers to let go of what they described as "*deeply held beliefs and practices"* related to teaching and learning and pedagogical practices. Also, only one participant specifically mentioned assessment and current assessment practices.

Given the limited support for some of the listed requirements, a further analysis of the responses was undertaken to determine if particular responses had a level of similarity that would enable them to be grouped together. From this analysis, three qualitatively distinct groups of requirements emerged. These were:

i. Delivery and implementation which included requirements b, f and i from Table 5.2;
ii. Resources which included requirements c, e, g and h from Table 5.2;
iii. Curriculum which included requirements a and d from Table 5.2.

The participants responses are presented in the table below.

**Table 5.3 Grouped requirements for the implementation of the purposes of STEM Education**

| Grouped requirements for STEM education | Participants who included the requirement |
|---|---|
| i) Delivery and implementation which included multiple approaches, for example problem- solving projects, applied investigations with an emphasis on relevance to students and authentic teaching, learning and assessment in and across the disciplines. | A, B, E, F, G, K, L |
| ii) Resources which included high-quality continuous professional development/learning for post and pre-service teachers, working collaboratively and in teams, partnerships between schools and with organisations and support materials developed using evidence. | A, B, C, E, G, H, K, L, P |
| iii) Curriculum which included interdisciplinary learning or integration of learning areas, foundational studies in science and mathematics, transdisciplinary and disciplinary knowledge and skills and innovative and applicable EY-12 and authentic assessment. | A, B, C, D, E, F, G, H, K, L, P |

Three participants nominated a particular pedagogical approach for the implementation of STEM education that included a reference to teaching across the STEM disciplines. Where these participants linked the particular pedagogical approach to authentic teaching and learning, their responses have been included with the first requirement.

Three participants did not specifically list professional development as a requirement, but rather focussed on the development and content curriculum. Where these participants referenced how the curriculum was to be delivered, their responses have been included with the second requirement.

There were five responses to the requirements for STEM education that did not immediately fit with at least one of the grouped requirements. Further analysis of these responses was undertaken to determine if these responses could be assigned to one or more of the grouped requirements. The results of this analysis are discussed below.

Participant B included in their response "*shift from content knowledge to process skills".* This response was seen as belonging to two of the grouped requirements. If this response was seen as representing changes in pedagogical approach, then it would align with the first grouped requirement of delivery and implementation. However, if this response was seen as moving the emphasis from just teaching and learning of content knowledge to

including the development of process skills in the curriculum, then it would align with the curriculum group requirement. These responses were then included in Table 5.3.

Participant E referenced "*alignment to student capability*." If this response equated to student achievement or outcomes as in the standards-based current Australian Curriculum, the response would align with the grouped requirements of delivery and implementation and curriculum. This response was then included in Table 5.3.

Participant E also referenced the need for a "*common strategic framework"* which was reflective of the current political and economic environment where accountability is measured in terms of successful outcomes against funding expended on education. This response would then align with all three groups. Participant E had already listed resources as a requirement.

Participant H referenced the use of "*real-world examples".* If this response was equated to the elaborations provided in the Australian Curriculum, then the response would align with the grouped requirement of curriculum. This response was then included in Table 5.3.

Participant L specifically referenced assessment as part of "*authentic teaching and learning"* as necessary for the implementation of STEM education. This response would align with the grouped requirements of delivery, implementation and curriculum. Participant L had already listed resources and curriculum as requirements.

The three groups of requirements shown in Table 5.3 were inclusive the themes curriculum and assessment from the document analysis, curriculum and assessment. The other three themes of pedagogy, engagement of students and access and equity of access from the document analysis could be considered as being implicit in the multiple approaches from delivery, implementation and in professional development/learning and working in teams from resources.

All eleven participants supported curriculum as included in Requirement iii). Nine participants supported the provision of resources as included in Requirement ii). Seven participants supported the delivery and implementation of STEM education as included in Requirement i). Both requirements i) and ii) addressed the themes of access and equity of access, engagement of students and pedagogy through the provision and delivery of content and tasks that were relevant to all students.

One participant directly referenced assessment in response to this question, which was somewhat surprising given the current discussions about assessment, i.e. measuring student

achievement using NAPLAN and the PISA testing program is a priority for many state governments in Australia. Assessment was a theme that emerged from the document analysis, often with respect to innovative practices in the assessment of inquiry and investigation type tasks with a STEM focus.

### 5.1.3 Question 3

*How would you explain STEM education to someone who is not familiar with this term?*

Although the responses to this question were diverse, five distinct themes emerged from the participants' responses. First was the use of STEM as an acronym that can be understood differently by the public, from Participants B and H. Second were the relevant, contemporary connections between the four subjects or disciplines Science, Technology, Engineering and Mathematics from Participants L and P. Third was an acceptance that jobs in the future will require STEM knowledge and skills from Participants B, E and F. Fourth was that STEM presents an approach to thinking and to finding possible solutions to challenging issues now and into the future from Participants A, E, G and K. Fifth was presenting STEM education as enabling an integrated approach to teaching and learning to illustrate a way of thinking and working to solve problems as suggested by Participants C, D and E.

### 5.1.4 Question 4

*Any additional comments*

Four participants provided additional comments. Participants A and K highlighted their belief that STEM education is dependent on how it is conceptualised, by whom it is conceptualised and who is advocating for it and their position or authority. Participants G and K continued to raise concerns about what the emergence and implementation of STEM education might mean for the other subject disciplines. Participant F expressed concern about STEM education as a construct, how it would fit with school education and whether its inclusion would detract from building strong foundations in science and mathematics. The issues raised by these participants were further explored in the semi-structured interviews.

The additional comments provided here, when considered with the responses to Questions 1, 2 and 3 point to STEM education as having multiple conceptualisations and modes of implementation

### 5.1.5 Conceptualisation of STEM education

The analysis of the data from Questionnaire One was used to construct the following conceptualisations of STEM education for each of the Delphi study participants.

Participant A presented STEM education as being context dependent in the different systems and jurisdictions and political and personal in nature. It included authentic learning in real-world problems with a focus on economic growth, student engagement and student access and was seen as having a social and societal purpose. Participant A suggested that STEM education be extended as it:

> Involves real-world interdisciplinary thinking, project-based tasks, design challenges, innovation and innovative thinking. … projects that draw on the STEM disciplines and have a social purpose and so involve other disciplines …

In contrast, Participant B argued that STEM education is driven by the economic and political agenda including work and employment offerings in a modern society. Participant B also suggested that this would require a greater emphasis on specific skills and levels of knowledge and the associated pedagogical practices because STEM is an "acronym for four fields of knowledge, important to modern society and economy and skills".

Supporting Participant's B comments, Participant C saw an economic function for STEM education but focussed on the use of an integrative approach to build student understanding and engagement with relevance to their future work and careers:

> Curriculum supportive of integrated approach to STEM education and …From the primary school education context, STEM education is an integrated approach that uses a strong narrative from the one of the four disciplines.

Participant D argued for a STEM education that requires an innovative curriculum that uses a transdisciplinary pedagogy and reimagines the knowledge and skills associated with the disciplines, moving beyond just a STEM focus and is matched to students' interests and society. By opening up the acronym:

> Interdisciplinarity- integration of learning areas to develop transdisciplinary and disciplinary knowledge and skills; outcomes-based approach … Acronym conveys different meanings to different people, needs to be 'disrupted' to support other innovative approaches to curriculum integration (e.g. STEAM, STREAM, STEMM).

Participant E acknowledged that STEM education with its strategic political and economic focus is of benefit to all in the community by providing the skills to solve problems relevant to society, for employment and well-being, now and into the future:

> Create new knowledge to improve world/solve problems, workforce with skills – job capable now and future Increase community participation STEM subjects and general enjoyment hobbies…. Support teachers and parents (home learning in STEM) … and 50% new jobs need STEM skills.

For Participant F, STEM education improved the workplace skills of others. Employers, economists, politicians and discipline-based academics see these skills as relevant to and necessary for an information rich modern society. In schools these are best delivered using foundation studies in science and mathematics:

> Making four disciplines more relevant to future workplace demands of an information-rich society and …STEM is an industry or university construct. In school setting science and mathematics are the two foundation discipline studies.

Participant F, unlike Participant C, was concerned with an integrated approach to STEM education and suggested instead "problem solving approach to studying concepts and principles but not through an integrated approach that has in the past lacked rigour".

Related to Participant A, Participant G, considered that STEM education introduces knowledge and ways of thinking about STEM, themselves and the world. This included applied investigations using examples from interdisciplinarity to build students' capabilities to solve problems in a changing world:

> To introduce students to knowledge and ways of thinking, the contributions to the world of the four disciplines. Develop students' competencies in these areas as in interdisciplinary set, develop problem-solving approaches for future in a changing world.

Participant G was also concerned about the impact of STEM education on other disciplines as it "reflects existing cultural norm that roughly classifies studies into science or arts and parents and some teachers see their children as having the skills of one or the other".

Participant H was particularly interested in the inclusion of mathematics in STEM education and argued that it contributes to our understanding of the world, making it a better place and supports the development of generic skills. Participant H explained that mathematics could be used anywhere and by other disciplines, was relevant to "science and

the whole community" and that "real-world examples and teacher passion can instil understanding".

Participant K, in describing STEM education, used the term "*eventful learning"* where problem solving across traditional boundaries is used to support and to engage students with the STEM disciplines and related employment through:

> Practices, literacies and dispositions in/towards each discipline with focus on problem solving to attract interest in STEM and employment in STEM, communication skills for different audiences.

and was

> dependent on the meaning of STEM education which is different for different people. What about other disciplines?

Participant L believed that STEM education presents connections between the disciplines through the use of inquiry learning to engage students with their world and future employment where:

> Authentic teaching and learning and assessment that draws knowledge from across the STEM subjects, new ways of knowing and letting go deeply held beliefs and practices

and

> In schools STEM education looks at ways to connect these four subjects to add meaning and relevance for students.

Participant P suggested that STEM education supports the participation of people in the economy and in a science and technology rich society. To do this effectively requires a well-resourced and innovative curriculum from Early Years to Year 12, implemented by well qualified and prepared teachers because it:

> … provides necessary knowledge, skills and understanding to operate effectively as both a participant in the economy and as a citizen in a science and technology rich society. (STEM education) also provides the specialists society requires.

The similarities between the participants' conceptualisation of STEM education usually clustered around a concept or idea. For example, Participants B and E focussed on economics and Participants F, K and L included employment and workplace skills which could be seen as examples of the economic and political drivers of STEM education. In contrast,

Participants A and H, in highlighting engagement with problems and issues of the real-world and Participants D and P, in emphasising an innovative curriculum all focussed attention on the content of programs as integral to the implementation of STEM education. Similarly, Participants C, G, H and K, by drawing attention to pedagogical practices and the relationships between the disciplines, also focussed on the practices required to implement STEM education. All participants were concerned with providing access and equity of access to all students. The four themes identified in the document analysis were visible in the conceptualisations of STEM education. Although only Participant L specifically included assessment, other participants alluded to it when referring to giving students opportunities to draw on the STEM disciplines to develop and present possible solutions to problems or issues that are relevant to them as referenced by the participants.

### 5.1.6 Summary of findings from Questionnaire 1

Each participant's conceptualisation of STEM education was unique and shaped by their particular beliefs and experiences as reflected in the diverse range of responses to the four questions asked in this questionnaire. For example, some participants who shared particular purposes for STEM education did not always share the same requirements necessary for the implementation of the purposes listed. What was clear is that STEM education means different things to different people, so it is context and person dependent and this impacts on approaches to its implementation.

The themes of engagement of students, access and equity of access, curriculum, pedagogy and assessment were present in the purposes and requirements for STEM education. This was consistent with the findings from the document analysis. In addition, as part of how the participants conceptualised STEM education, three additional themes emerged. These were the benefit of the community or society, an uncertain and changing future and addressing current or real-world issues.

## 5.2 Findings from Questionnaire 2

In the second questionnaire the participants were able to see how their responses and those from other participants were brought together in the lists of purposes and requirements provided. Participants were asked to rank a list of purposes of STEM education and to assign priorities to a list of requirements for the implementation of STEM education.

### 5.2.1 Question 1

*Responses to Q1 on Questionnaire 1 (the purpose(s) of STEM education) have been collated to form the list below. Please rank these from 1 to 6 where 1 is the most important for you and 6 is least important for you.*

The participants' responses are represented in the table below.

**Table 5.4: Purposes of STEM education and participant ranking from high (1) to low (6)**

| **Purpose: STEM education/Rank** | **1 High** | **2** | **3** | **4** | **5** | **6 Low** |
|---|---|---|---|---|---|---|
| 1: Equip people with the knowledge and skills necessary to drive economic and social prosperity in the 21st Century technology rich workplaces and careers | B, E, H, P | G | A, C | F | L | Nil |
| 2: Build students' understanding of the world around them and how they can contribute to making it a sustainable place to live now and into the future | G | C, H, P, L | Nil | A, E, K | B | F |
| 3: Provide pathways for entry into the digital workforce and for the next generation of specialists in STEM fields. | A, C | E | B, G, H, P | L | K | F |
| 4: Engage students with 'real-world problems' that require input from each of Science, Technology, Engineering, and Mathematics to solve | F | G | C, E, L | H | P | A, K |
| 5: Improve access to careers in STEM fields for previously under-represented groups (for example girls/women, rural, indigenous) | L | Nil | B, K | Nil | C, F | E, G, H, P |
| 6: Introduce students to the use of evidence to make ethical decisions about contemporary and complex issues | Nil | Nil | F, K | C, P | A, E, G, H | L |

In responding to this question, two participants took a different approach to ranking the listed purposes. Participant B chose to rank only three of the purposes using a ranking of 1, 2 and 3. This data was included in Table 5.4. The three purposes that Participant B ranked all focussed on building future economic and social prosperity. Participant B provided the following explanation for this response as being "very concerned at who (and why) is driving STEM education and impact on education".

Participant D ranked all six purposes as high and in so doing was the only participant who ranked Purpose 6 as high. This response was illustrative of the participant's stance that all areas of the curriculum contribute to the education of young people. This data was not included in Table 5.4. Participant D provided the following explanation for their response:

> I believe that all these purposes are equally important in helping to prepare young people (from ECE to HE to teacher PD)* as future citizens and workers armed with appropriate

disciplinary knowledge and advanced transformational values and skills to engage successfully in a complex, chaotic, crisis-ridden and rapidly changing world.

*ECE represents Early Childhood Education, HE represents Higher Education and teacher PD represents Professional development for teachers

These two responses from Participants B and D illustrated how the conceptualisation of STEM education is very much dependent on and reflective of personal beliefs and was built from the individual's experience and position.

Given the spread of rankings provided by the participants to some of the purposes listed, it was decided to reduce the number of rankings from six to three where:

- high was assigned to those purposes initially ranked as 1 or 2;
- medium was assigned to those purposes initially ranked as 3 or 4;
- low was assigned to those purposes initially ranked 5 or 6.

This data is presented in Table 5.5.

**Table 5.5 Purposes of STEM education and participant ranking as High, Medium or Low***

| **Purpose: STEM education/Rank** | **High** | **Medium** | **Low** |
|---|---|---|---|
| 1: Equip people with the knowledge and skills necessary to drive economic and social prosperity in the 21st Century technology rich workplaces and careers | B, E, G, H, P | A, C, F | L |
| 2: Build students' understanding of the world around them and how they can contribute to making it a sustainable place to live now and into the future | C, G, H, P, L | A, E, K | B, F |
| 3: Provide pathways for entry into the digital workforce and for the next generation of specialists in STEM fields. | A, C, E | B, G, H, L, P | F, K |
| 4: Engage students with 'real-world problems' that require input from each of Science, Technology, Engineering, and Mathematics to solve | F, G | C, E, H, L | A, K, P |
| 5: Improve access to careers in STEM fields for previously under-represented groups (for example girls/women, rural, indigenous) | L | B, K | C, E, F, G, H, P |
| 6: Introduce students to the use of evidence to make ethical decisions about contemporary and complex issues | Nil | C, F, K, P | A, E, G, H, K, L |

*Excluding the responses from participant D (as previously noted).

The responses to this question were recorded as high which represented an initial ranking of 1 or 2, as medium which represented an initial ranking of 3 or 4, or as low which represented an initial ranking of 5 or 6, as shown in Table 5.5.

The two purposes of STEM education ranked as high were:

Purpose 1: *equip people with the knowledge and skills necessary to drive economic and social prosperity in the 21st Century technology rich workplaces and careers* and;

Purpose 2: *build students' understanding of the world around them and how they can contribute to making it a sustainable place to live now and into the future.*

This was consistent with the policies and statements developed for Australia including the National STEM School Education Strategy (ECA, 2015) and Engineers Make Things Happen (EA, 2017). Both of these documents had a focus on building the knowledge and skills of all young Australians required to ensure Australia's ongoing economic prosperity and to meet future challenges. This was also consistent with the international policies, *STEM 2026. A Vision for Innovation in STEM education* (2016) from the USA and *The report of the STEM Review* (2009) from the UK.

In support of a high ranking for Purpose 1, Participant E suggested in that it "is the overarching goal without which we won't have the economy to enable greater sustainability".

In support of a high ranking for Purpose 2, Participant L commented that "STEM education is about solving real-world problems using the disciplines of science, technology, engineering and mathematics". Both these responses focussed on the world students are likely to face in the future. However, a contrary response was provided by participant K who scored a lower ranking for Purpose 1 and sounded a cautionary note on the need to focus on students' needs and interests now and not just into their futures

> While providing opportunities for students to prepare for future careers in STEM is a necessary part of a school education, this is not the major issue for all students in schools.

The two purposes for STEM education ranked as medium were:

Purpose 3: *provide pathways for entry into the digital workforce and for the next generation of specialists in STEM fields;* and

Purpose 4: *engage students with 'real-world problems' that require input from each of Science, Technology, Engineering, and Mathematics to solve*.

Purpose 3 focussed on the current and future employment, the economic and social prosperity and the type of education required to deliver appropriately skilled workers. This could be seen as adding the digital component associated with current and future employment to and expanding Purpose 1, which was also consistent with students needing particular experiences to contribute to solving problems and then implementing the solutions within the local, national and international environments.

Participant L, in supporting a medium ranking for Purpose 3, suggested:

> Building pathways into STEM Careers should not just be about 'digital' but also about all kinds of STEM work. We need greater collaboration between industry and education so we can share information and work together to look at the types of pathways that might be possible.

Purpose 4 focussed on how solving problems that are relevant to students and their futures engages them with STEM education and illustrates how each of the disciplines of STEM education work together. This could also be seen as a component of Purpose 2. In supporting a medium ranking for Purpose 4, Participant E explained that it "makes the career connection". Participants L provided a similar response suggesting that "although a STEM careers component is worthwhile, other purposes of STEM education are more important"; however, Participant P offered an alternate view about Purpose 4 and gave it a low ranking:

> The reason for my 6th ranking is that 'engagement' is a weak purpose statement. It is rather a technique or strategy to achieve a learning purpose, it can hardly stand as that purpose.

This suggested that engagement of students is evidence that a purpose has been implemented rather than of the purpose itself and as such was contrary to statements made in some published documents related to STEM education. Rather than a purpose, perhaps the level of engagement students demonstrate could be a measurable outcome of STEM education programs.

The two purposes of STEM education ranked as low were:

Purpose 5: *improve access to careers in STEM fields for previously under-represented groups (for example girls or women, rural and indigenous);* and

Purpose 6: *introduce students to the use of evidence to make ethical decisions about contemporary and complex issues.*

For Purpose 5 this low ranking was surprising as it is one of the most often cited purposes of STEM education in published documents authored by governments, business, industry, the Chief Scientist Australia and professional associations.

However, Participant H offered the following explanation and an alternative view for the low ranking:

> I don't think the purpose of STEM education is to improve access to careers for under-represented groups. But I do think that these groups should be encouraged and inspired to learn STEM education. They also need equal access to STEM education.

This appeared to suggest that if STEM education is made available to all then it is the mode of delivery that matters when trying to improve access to careers for particular groups. If STEM education is regarded as essential for all, then ways must be found to provide access for all.

Some participants explained their low ranking of Purpose 6 was due to the lack of a specific reference to STEM education. However, several participants commented that use of evidence and making ethical decisions should be included in all education programs, not just those for STEM education.

Many of the participants in this study have held or continue to hold senior positions in education, which suggested that their focus may have been on the education component of STEM education. This may explain why they regarded Purposes 5 and 6 as being of lower importance when compared with the other listed purposes of STEM education. It may also explain the higher importance assigned to those purposes that had a specific reference to education and people.

An alternate perspective to the purposes of STEM education was provided by Participant B and related to the political nature of STEM education. He believed that assigning any other purpose to STEM education that did not address the agenda or interests as express by governments, business or industry was *"wrong"*. This was similar to the response from a different participant on Questionnaire 1 where they suggested "*STEM is a university/industry construct"*.

### 5.2.2 Question 2

*Responses to Q1 on Questionnaire 1 (requirements for the implementation of STEM education in the Australian context) have been collated to form the list below. What level of*

*priority, if any from 1 (highest) to 5 (lowest), would you assign to each one?* (same number can be used more than once).

The participants' responses are shown in the table below.

**Table 5.6 Requirements for STEM education and participant ranking from high (1) to low (6)**

| **Requirement /Priority** | **1 High** | **2** | **3** | **4** | **5 Low** |
|---|---|---|---|---|---|
| 1: A shift from a focus of acquiring specific content knowledge to the achievement of outcomes where acquisition of skills has a greater importance in the development of curriculum and assessment tasks. | B, C, F | A | G | H, L | K, P |
| 2: Sustainable partnerships between schools, universities, TAFEs and industry/business as applicable that support and collaborate on the delivery of high-quality STEM education in schools. | E | B, C | G, H, L, P | Nil | A, F, K |
| 3: Use of age appropriate applied investigations and activities to demonstrate how knowledge and skills from multiple disciplines are used to solve problems. | C, E, H, L | F, K | P | A | G |
| 4: Development of a transdisciplinary approach to teaching and learning that incorporates the elements of STEM disciplines and draws from other disciplines as required to investigate issues important to students/community | A, C, K, L | G | Nil | F, P | Nil |
| 5: Development of a curriculum for Early Years to Year 12 that links learning areas (disciplines) in ways that support students to solve 'real-world problems'. | C, K, L | H | A, B, F, P | G | Nil |
| 6: Building community understanding of the relationship between studying STEM subjects and future employment including supporting parents to become STEM aware. | E | P | C, H, L | G | A, F, K |
| 7: Review of assessment requirements of senior secondary STEM subjects to accommodate projects completed using an inter-disciplinary approach | E, H | C | P | G, K | A, F, L |

In responding to this question, three participants mis-read the instructions and assigned priorities of 1 to 7 to the listed requirements rather than from to 1 to 5. Assigning a priority of 6 or 7 to any requirement was interpreted as evidence that the participants regarded the respective requirement as being of low to very low importance. This led to the decision to include such data and assign it as a priority of 5 in Table 5.6.

As for question 1, Participant D assigned all requirements with a high a priority. This data were not included in Table 5.6 or Table 5.7.

Participant D provided the following explanation for this response:

> Australian Science Curriculum in the form of the Science As A Human Endeavour (SHE) strand and together with the General Capabilities and Cross-Curriculum Priorities, the SHE strand provides a powerful transdisciplinary perspective that should 'infect' interdisciplinary curriculum planning which aspires to integrate Science with not only Technology, Engineering and Mathematics (and Medicine) but also with the Arts and Humanities. In practice, teachers could engage creatively in forms of STEM curriculum integration, ranging from conservative (for example, STEM) to more comprehensive forms (for example, ST2EAM, ArtSTEM, STEAM).

This comment further illustrated Participant D's strong commitment to moving to a transdisciplinary perspective of curriculum that encompasses all the disciplines and so moves beyond the current use of set achievement standards for specific disciplines. The responses provided by Participant D in Questions one and two were further explored in their semi-structured interview.

Three participants also took a different approach to that of other participants when responding to this question. Participant E assigned a priority of 1 to the requirements 2, 3, 6 and 7 only. These data were included in Table 5.6 and Participant E provided the following explanation for their response. "I regarded statements 3 and 4 as variations of interdisciplinary pedagogy". This comment illustrated the different ways in which particular concepts are understood and how the use of particular terms in education is dependent on the individual's stance. This participant did not have a background in education and took a much broader perspective of what interdisciplinary pedagogy included.

Participant G and Participant P did not assign a priority of 1 to any of the listed requirements. Both of these participants reflected on the lack of success of past attempts at interdisciplinary education and the lack of understanding of the epistemology of the disciplines. They did however assign priorities to the other requirements and these data were

included in Table 5.6. and Table 5.7. Their reasons for this response were further explored in the semi-structured interviews with each of these participants.

Given the spread of priorities that participants assigned to the requirements listed, it was decided to undertake a further analysis similar to that completed for question one. This reduced the number of rankings from six to three where

- high was assigned to those requirements initially ranked as 1 or 2;
- medium was assigned to those requirements initially ranked as 3 or 4;
- low was assigned to those requirements initially ranked 5.

These data are shown in Table 5.7.

**Table 5.7 Requirements for STEM education and participant ranking as High, Medium or Low***

| Requirement | High | Medium | Low |
|---|---|---|---|
| 1: A shift from a focus of acquiring specific content knowledge to the achievement of outcomes where acquisition of skills has a greater importance in the development of curriculum and assessment tasks. | A, B, C, F | G, H, L | K, P |
| 2: Sustainable partnerships between schools, universities, TAFEs and industry/business as applicable that support and collaborate on the delivery of high-quality STEM education in schools. | B, C, E | G, H, L, P | A, F, K |
| 3: Use of age appropriate applied investigations and activities to demonstrate how knowledge and skills from multiple disciplines are used to solve problems. | C, E, F, H, K, L | A, P | G |
| 4: Development of a transdisciplinary approach to teaching and learning that incorporates the elements of STEM disciplines and draws from other disciplines as required to investigate issues important to students/community. | A, C, G, L, K | F, P | Nil |
| 5: Development of a curriculum for Early Years to Year 12 that links learning areas (disciplines) in ways that support students to solve 'real-world' problems. | C, H, K, L | A, B, F, G, P | Nil |
| 6: Building community understanding of the relationship between studying STEM subjects and future employment including supporting parents to become STEM aware. | E, P | C, H, G, L | A, F, K |
| 7: Review of assessment requirements of senior secondary STEM subjects to accommodate projects completed using an inter-disciplinary approach. | E, H | C, P | A, G, K, L, P |

*Excluding the responses from participant D (as previously noted).

Eight participants assigned a high or medium priority to Requirement 3*: Use of age appropriate applied investigations and activities to demonstrate how knowledge and skills from multiple disciplines are used to solve problems.* This requirement focussed on teaching and learning and investigating issues important to students and the community.

Participant C in support of a high priority for Requirement 3 responded "in order to achieve a complete education, students need to build an understanding of integration within the constituent disciplines". Participants who assigned a high priority to this requirement generally believed that it provided a way to make STEM education real and meaningful for students and was consistent with their responses to Question 1. This requirement also attracted one of the lowest priorities from Participant A who explained that this requirement represented "the narrower view of STEM as specific activities within the curriculum" and "doesn't tackle the broader purpose of STEM education".

Seven participants assigned either a high or medium priority to Requirement 4: *Develop a transdisciplinary approach to teaching and learning that incorporates the elements of STEM disciplines and draws from other disciplines as required to investigate issues important to students and community*. This requirement focussed on making meaningful connections between the STEM disciplines and other disciplines that support students' learning and as such is also consistent with the responses from question 1.

In assigning a high priority to Requirement 4, Participant A explained that it "captures the idea of drawing on multiple disciplines while maintaining disciplinary integrity".

However, Participant L assigned a medium priority for this requirement because it:

> Overstates the importance of transdisciplinary approaches. In school education, the development of the understandings, structure and unique insights of the constituent disciplines is key to improving learning.

Most participants assigned a medium or high priority for Requirement 5: *Development of a curriculum for Early Years to Year 12 that links learning areas and disciplines in ways that support students to solve 'real world' problems.* The reasons provided by the participants for assigning these priorities identified the importance of a curriculum that linked subjects or made explicit the connections between STEM subjects and other subjects for teachers when designing programs for their students. One participant, Participant G who assigned a medium priority to this requirement cautioned:

> Active learning is important – but not everything students need can be immediately posed as a 'real world' problem. We've had cycles of attempts to do this many times before and it has the potential to be superficial.

Requirements 1, 2, 6 and 7 elicited a range of diverse priorities from the participants. Requirement 1: *A shift from a focus of acquiring specific content knowledge to the achievement of outcomes where acquisition of skills has a greater importance in the development of curriculum and assessment tasks.* This requirement attracted four high, three medium and two low priorities. The reasons provided were reflective of the current debates surrounding STEM education. These were related to which mode of delivery best suits STEM education - multi-disciplinary, transdisciplinary, inter-disciplinary or integrated approaches, the value and place of specific content knowledge, whether the acquisition of skills is to be taught or if this occurs organically by doing investigations, the activities involved or solving problems. Participant H focussed on knowledge and understanding as being the most important, so assigned it a high priority because "acquiring knowledge should require understanding that knowledge". However, Participant P assigned a low priority to this requirement because:

> The underlying assumption here rests on a false dichotomy between knowledge and skills. I believe it is fundamentally flawed to conceive of skills being developed independently from key conceptual knowledge.

Requirement 2: *Sustainable partnerships between schools, universities, TAFEs and industry/business as applicable that support and collaborate on the delivery of high-quality STEM education in schools.* This requirement attracted three high, four medium and three low priorities. The reasons provided focussed mainly on involving or engaging the whole community in all aspects of STEM education to improve connections between school, higher education, business and industry and to make STEM education real.

However, Participant K was cautious about the potential and possibilities for partnerships and therefore assigned a low priority to this requirement as "partnerships could be very useful in providing contexts for projects and assistance in the development of challenging projects".

Requirement 6: *Building community understanding of the relationship between studying STEM subjects and future employment including supporting parents to become STEM aware.* This requirement attracted two high, four medium and three low priorities. The reasons

focussed on the need to inform parents about the importance of STEM education and the opportunities it provides for students. Overall this requirement was as seen as less important than other requirements. Participant K assigned this requirement a low priority because "this will happen eventually over time as schools shift towards authentic learning practices".

Requirement 7: *Review of assessment requirements of senior secondary STEM subjects to accommodate projects completed using an inter-disciplinary approach.* This requirement attracted the greatest number of low priorities with five but also attracted two high and two medium priorities. In assigning a low priority, Participant L responded "while I quite like this idea, this would require a very different approach to senior secondary schooling. I would prefer to address the other ideas before this one".

The other ideas referred to in this quote included age appropriate investigations from Requirement 3 to which this participant assigned a high priority. Participant L had listed assessment practices as something that need attention on Questionnaire 1. This response suggested that for Participant L, the priority for the implementation of STEM education was in primary to middle school secondary education where assessment practices are more flexible, without the external assessments included in the senior secondary years of schooling.

In assigning a high priority to this requirement, Participant H identified that:

> Assessment is important so hopefully if we implement age appropriate investigations and activities to demonstrate how knowledge and skills from multiple disciplines are used to solve problems, we will assess them appropriately. The two are linked.

Like Participant H, Participant E also expressed similar concerns about assessment for STEM education and rated it as a high priority.

Although there was a marked difference in the priority assigned to Requirement 7, Participants E, H and L shared similar ideas about implementation but not necessarily about the most important purpose of STEM education. Also, Participants A, F and K placed a low priority on Requirements 2 and 3, both of which had a focus on partnerships between business, industry the community and education to implement STEM education. This was initially surprising given their experiences and research interests. This was not interpreted as a negative reflection of the value of partnerships, but rather that these participants regarded other requirements as being of a higher importance for the implementation of STEM education in the Australian context.

### 5.2.3 Question 3

*Any additional comments*

Seven participants provided additional comments. The comments related to the ambiguity in the meaning for STEM education amongst different stakeholders and the need to build teacher capacity to implement STEM education for all young Australians.

The additional comments suggested what the participants believed should be fundamental to STEM education and as such provided pointers to consider when constructing a vision for STEM education in the Australian context. These included a vision is that broad and includes all stakeholders, encompasses education for all, captures and fosters the integrated nature of STEM education, is holistic and inclusive and has a sense of purpose that sustains future economic growth and social prosperity.

One participant voiced concerns about the impact STEM education could have on what has been achieved in recent science initiatives such as the increasing use of the inquiry-based approach to building knowledge and skills rather than rote learning of facts or the use of contexts and assessment tasks that engage students. This provided a cautionary note that before implementing something new, previous gains should be acknowledged and be reflected within development and implementation of STEM education programs.

### 5.2.3 Summary of findings from Questionnaire 2

The analysis of the data showed that participants who ranked the same purposes for STEM education as high did so for different reasons. Some participants who had ranked the same purposes as high chose different requirements or assigned different priorities to the same requirements. The reasons participants gave for assigning a high or low priority to particular requirements varied regardless of how they previously ranked the purposes associated with the requirements. This suggested that any vision constructed for STEM education in Australia would need to be flexible so that it could accommodate the different conceptualisations of STEM education held by those advocating for STEM education or who have an interest in or responsibility for it.

When constructing possible visions for STEM education from the analysis of data Questionnaires One and Two, it was apparent that each vision was inclusive of multiple purposes of and the requirements for STEM education. Any of the visions constructed would therefore need to support a cohesive and inclusive STEM education that would assist all

young Australians to meet future challenges and to ensure sustainable economic prosperity within a changing world.

### 5.3 Findings from Questionnaire 3

In this third questionnaire participants were asked to choose their preferred vision from the three presented and which pivotal statements from a list provided underpinned this choice. Participants were able to amend the vision they chose and to write their own supporting pivotal statement.

#### 5.3.1 Question 1

*Three potential visions for STEM education in the Australian context are presented below. These visions have been constructed from the analysis of data provided by the participants in response to Questionnaires 1 and 2. Which vision best aligns with YOUR preferred vision for STEM education in the Australian context?*

The participants' responses are represented in the table below.

**Table 5.8 Summary of the choice of preferred Vision**

| **Vision** | **Participant** |
|---|---|
| Vision 1: *STEM education contributes to a broad suite of learning experiences that enable all young people to participate in and contribute to building sustainable communities.* | B, E, (L)* |
| Vision 2: *STEM education provides the skills that enable all young people to contribute to growing the nation's economy and global competitiveness.* | H |
| Vision 3: *STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they live now and into the future.* | A, C, D, F, G, K, P, (L)* |

* Participant L chose both Vision 1 and Vision 3.

Participant L explained:

> Because of the notion of understanding the complex and challenging nature of the world we live in – this is clearly connected to the first vision and the notion of sustainability, so I am having trouble separating these two visions.

This suggested that for this participant, STEM education is integral to a sustainable future for young people.

The participants who chose Vision 3 did so as it focussed on the knowledge and skills students will need to manage the challenges of the future and be able to make informed decisions.

Participant G, in choosing Vision 3, also offered an additional and different comment as a cautionary note that education is complex and therefore trying to find a single solution to identified issues is problematic:

> Like a lot of education rhetoric, it (STEM education) is a bit overblown and a bit too suggestive of the naïve idea that if we only teach x the world's problems will be solved, and all people will have fair and good lives. But it is in line with the way curriculum rationales tend to be written, so not suggesting a specific change.

In choosing Vision 1, Participants B and E focussed on the link between STEM education and employment that enables young people to build and contribute to their communities.

In choosing Vision 2, Participant H focussed on building the skills young people will need to contribute to the nation's economy now and into the future. Participant H also provided an additional comment that was very different from those of most other participants. Participant H suggested that having positive skills places young Australians at the centre of STEM education:

> In an ideal world, the job that a young person with STEM skills will have will be one which will ensure the world is a better place to live in, which would include, for example, sustainability. I also definitely believe that having STEM skills enables one to have some understanding of complex problems that must be tackled e.g. climate change.

The vision preferred by the most participants was Vision 3: *STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they live now and into the future*.

This was likely due to the inclusion of knowledge, skills and understanding and the nature of students' world now and into the future in the vision statement. This vision also hinted at the resilience required by young people to embrace and manage change. Two examples that reflected why participants preferred this vision are shown below.

Participant P, in support of this vision explained “it is the most ambitious in scope and it specifically identifies knowledge as well as skills and certainly better than ‘learning experiences”. Participant K explained that this vision “best matches my beliefs about the purpose of education and science education specifically”.

However, in deciding against Vision 3, Participant B argued for a “wider goal for education for all young people at school but this is not achievable by the STEM subjects alone”. Participant E also decided against Vision 3 because it “lacks the action let’s do it orientation that I observe in young people”.

Three participants (including one who had also chosen Vision 3), chose Vision 1: *STEM education contributes to a broad suite of learning experiences that enable all young people to participate in and contribute to building sustainable communities.*

This was likely due to an emphasis on all young people and the focus on the breadth of experiences and opportunities provided to young people in the vision statement. This vision also supports young people to be active participants in their communities and reflects sustainability as an issue that is relevant to and of importance to young people.

In supporting this vision, Participant E explained that it was “applicable broad curriculum and best summarises/reflects the breadth/enabling benefit of STEM education together with action and social values.” In contrast, Participant G suggested that it “seems rhetorical and without much specific substance.”

Overall, the lack of reference to knowledge, skills and understanding, the use of the vague term “*learning experiences*” and a perception that sustainable communities referred to more local applications rather than to a global sustainable community was likely to have restricted the appeal of this vision to the participants.

One participant preferred Vision 2**:** *STEM education provides the skills that enable all young people to contribute to growing the nation’s economy and global competitiveness.* Participant H supported this vision “because I believe that many jobs in the future will rely on STEM skills”. However, in deciding against this vision Participant E explained that it “lacks the social values that I see strongly present in young people.”

In Vision 2 there was an emphasis of including or reaching all young people and the importance of STEM education to their future which was similar to Vision 1. However, due to the focus on economic prosperity through the development of skills, the reference to knowledge or community most likely made Vision 2 less appealing to participants.

#### *5.3.1.1 Why did a participant choose a particular vision?*

The similarities in the reasons given by the participants for their choice of preferred vision are explored below.

For example, Participants A, C and D chose Vision 3 because it reflected their opinion that STEM education was supporting the development of forward or future looking thinkers better equipped to manage their complex and challenging world.

Participant A focussed on:

> knowledge and skills for a complex and challenging world which is a personal benefit and one that is forward looking and acknowledges the important role played by STEM in defining future worlds and challenges.

Participant C focussed on:

> developing the skills in students to be able to negotiate an environment where being able to think critically is more important than ever.

Participant D focussed on:

> better prepar(ing) young people for a rapidly globalising world beset by an emerging digital economy and an ecological crisis.

In choosing Vision 3, Participant F, like participants A and D, provided a specific purpose for STEM education that supported students to make decisions; "the purpose of science education and by extension STEM education is to help students become scientifically literate". Similar to Participants A and K, Participant P drew attention to the importance of the scope of a vision for STEM education being more than aspirational and "most ambitious in scope and it specifically identifies knowledge as well as skills."

Although Participant K believed that STEM education was an essential component of the education for young people, they also provided a personal reason for choosing Vision 3 in that it "best matches my beliefs about the purpose of education and science education specifically".

In choosing Vision 1, Participants B and E saw STEM education as being a requirement for economic prosperity within the community and believed the vision should make this explicit. Participant B explained "it is limited to the STEM subjects being aimed at this (economic) outcome".

Like Participant A, C, K and P, Participant E considered that STEM education would assist young people contribute to their community by "developing the skills in students to be able to negotiate an environment where being able to think critically is more important than ever". Interestingly, Participants G and H provided a similar reason for their choice of vision, although each chose a different vision. They both focussed on the possible applications of STEM education and what these might deliver. Participant G, choosing Vision 3, suggested it was a "potential way of bringing the interdisciplinary application of the areas together".

In contrast, Participant H chose Vision 2 because it reflected a strongly held personal belief as "I definitely believe that having STEM skills enables one to have some understanding of complex problems that must be tackled e.g. climate change". In choosing both Visions 1 and 3, Participant L showed how components that mattered to a particular participant when present in two different visions could be combined by explaining that "the notion of sustainable communities requires understanding the complex and challenging nature of the world we live in".

In so doing, Participant L focussed on STEM education as developing connections between the STEM disciplines to understand the challenging and changing nature of the world and work. Participant L also saw STEM education as contributing to economic prosperity like Participants B, E and P and as developing thinking and problem-solving skills like Participants A, C and D and understanding the world like Participants G and H.

In choosing two visions Participant L demonstrated an example of a *critical* event as identified by Webster and Mertova (2007: p.79). Whilst the action of choosing two visions set the participant apart from the others it also demonstrated that an individual's conceptualisation of STEM education was complex and both informs and impacts on decisions made. It also suggested that it is possible for an individual to accept and blend the opinions of others and that visions could be merged.

The themes identified in the document analysis were evident in the reasons the participants provided for their choice of visions. The inclusion of knowledge, skills and understanding addresses curriculum content. Presenting connections between the STEM disciplines is an example of pedagogy and problem solving and is related to assessment practices. The consistent focus on supporting students to manage the challenging future that they are likely to face speaks to the engagement of students in learning that is relevant to

them and the provision of access and equity of access to opportunities to develop the knowledge and skills required.

### 5.3.2 Question 2

*To implement my preferred vision, it is pivotal …* To complete this sentence please tick up to three of the statements listed below and provide reason(s) for your choice.

The participants' responses are shown in the table below.

**Table 5.9 Summary of choice of Pivotal statements**

| Pivotal statement | Participant |
|---|---|
| 1. The curriculum for STEM education accommodates the development of knowledge and skills within each discipline and across the disciplines of STEM. | A, B, C, D, F, G, K, L, P |
| 2. The assessment practices for STEM education focus on the application of knowledge and skills to identify and solve 'real world' problems. | A, B, C, D, E, F, G, |
| 3. The pedagogical practices used to deliver STEM education inspire young people to choose STEM-related subjects at school and to pursue these into higher and/or further education and careers. | C, E, H, K, L |
| 4. Ongoing high-quality professional learning for teachers is provided that increases their competence and confidence (and experiences) in delivering STEM education. | A, B, C, D, E, G, H, L, P |
| 5. Implementation of STEM education is co-ordinated to maintain high-quality and consistency across jurisdictions. | C |
| 6. Informed communities actively support young people to consider pursuing STEM subjects, careers or employment. | Nil |
| 7. Employment opportunities are available that are attractive to young people who are job capable in STEM and STEM related fields. | H, P |
| 8. Own statement (not more than 25 words) | A, D, K |

Two participants provided unique and interesting responses to this question. Participant L, who chose both visions 1 and 3 selected the pivotal statements one, three and four to support the implementation of these two visions. However, no other participant chose this same combination of pivotal statements to support their choice of vision.

Participant E also preferred and recommended the use of capabilities rather than skills to better reflect move to job-capable rather than job-ready and noted that the statements 5, 6 and 7 were "important but secondary to the others and nice to have".

Statement 8: Own statement

Three participants, each of whom had chosen Vision 3, provided their own pivotal statements as included below.

Participant A suggested:

> We need committed research and development to explore the pedagogies and curriculum foci that are needed to effectively implement a visionary STEM education. This will only happen if we have agreement across state and national jurisdictions on the direction STEM education needs to go, and the development and maintenance of a long-term vision and plan to ensure change takes place, rather than the stop-start policy that exists currently around election cycles in the different states.

Participant D suggested:

> Interdisciplinary STEM curriculum planning should include the Arts and the Humanities. This would provide much richer contexts for developing knowledge and higher-order abilities, would better reflect the emerging world of transdisciplinary working environments and provide real-world scenarios for students to engage in values education.

Participant K suggested:

> The curriculum for STEM education focuses on the application of knowledge and skills to identify and solve 'real world' problems. This represents a combination of 1 and 2 above. This is the closest reason for promoting scientific literacy out of the choices. This is the most important.

These three statements focussed on curriculum and pedagogy and were grounded in developing authentic rich and real learning for all students and could be seen as extending of or providing greater direction or clarity to the pivotal statements one and three.

The most selected pivotal statements, with nine responses each, were Pivotal statement 1: *The curriculum for STEM education accommodates the development of knowledge and skills within each discipline and across the disciplines of STEM;* and

Pivotal statement 4: *Ongoing high-quality professional learning for teachers is provided that increases their competence and confidence (and experiences) in delivering STEM education.*

This next most selected pivotal statement with seven responses was Pivotal statement 2: *the assessment practices for STEM education focus on the application of knowledge and skills to identify and solve 'real world' problems related to assessment*.

There were five responses for Pivotal statement 3: *the pedagogical practices used to deliver STEM education inspire young people to choose STEM-related subjects at school and to pursue these into higher and/or further education and careers.*

The four statements were related to curriculum, assessment and pedagogy and this was consistent with three of the themes identified in the document analysis. Professional learning as identified in Pivotal statement 4 and the pedagogical practices included in Pivotal statement 3 were seen as supporting the provision of STEM education to all students. The themes of access and equity of access and engagement of students identified from document analysis were also represented in the most selected pivotal statements.

The least selected statements in descending order were Pivotal statement 7: *employment opportunities are available that are attractive to young people who are job capable in STEM and STEM related fiel*ds two responses, Pivotal statement 5: *implementation of STEM education is co-ordinated to maintain high-quality and consistency across jurisdictions* with one response and Pivotal statement 6: *informed communities actively support young people to consider pursuing STEM subjects, careers or employment*. The low rate of selections of these three pivotal statements was notable given that:

1. government policies, professional associations and industry statements include a focus on the relationship between STEM subjects, education, skills and future employment and jobs and economic and social prosperity;
2. the recent focus by governments, professional associations and the media on building community understanding of the importance of and need for STEM education for economic and social prosperity;
3. the emphasis on accountability for and improvement in student learning, outcomes, achievement and performance given the funds expended by governments on education and the recent Commonwealth Government report into educational achievement in Australian schools *Review to Achieve Educational Excellence in Australian Schools* (2018).

However, this low rate of selection did suggest that whilst there was a general acceptance of the political and economic drivers of STEM education by the participants, their focus was on students and what high-quality STEM education programs would offer students.

The participants' reasons for their choice of vision and their selection of pivotal statements enabled the assignment of pivotal statements to support a particular vision as shown in the Table 5.10.

**Table 5.10 Summary of Pivotal statements supporting the choice of a preferred Vision**

| **Vision** | **Pivotal statements** |
|---|---|
| Vision 1: *STEM education contributes to a broad suite of learning experiences that enable all young people to participate in and contribute to building sustainable communities.* | 1, 2, 3, 4 |
| Vision 2: *STEM education provides the skills that enable all young people to contribute to growing the nation's economy and global competitiveness.* | 3, 4, 7 |
| Vision 3: *STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they live now and into the future.* | 1, 2, 3, 4, 5, 7, 8 |

Although the combination of pivotal statements selected by participants to support the implementation of a particular vision varied, there were some commonalities.

The eight participants who selected Vision 3 also selected Pivotal statement 1 (curriculum focus) and six of these participants also selected Pivotal statement 2 (assessment focus). Vision 3 was also supported by Pivotal statements 3, 4, 5 and 7 (pedagogy focus, a professional development focus, related to the co-ordinated implementation of STEM education and employment and a focus on careers in STEM and STEM related fields, respectively). The Own statements (provided by three participants) all supported the choice of Vision 3.

The three participants who selected Vision 1 also selected Pivotal statement (professional development focus). Two of these participants also selected Pivotal statement 3 (pedagogy focus). Pivotal statement 1 (curriculum focus) and Pivotal statement 2 (assessment focus) were also used to support the choice of Vision 1.

For Vision 2, the participant selected Pivotal statements 3 (pedagogy focus), 4 (professional development focus) and Pivotal statement 7 (employment and careers in STEM

and STEM related fields). Interestingly, Pivotal statements 4 and 7 were used to support the choice of Vision 3, and Pivotal statements 3 and 4 were used to support the choice of Vision 1.

Only two pivotal statements were used to support the choice of each vision. These were Pivotal statement 3: *The pedagogical practices used to deliver STEM education inspire young people to choose STEM-related subjects at school and to pursue these into higher and/or further education and careers;* and

Pivotal statement 4: *Ongoing high-quality professional learning for teachers is provided that increases their competence and confidence (and experiences) in delivering STEM education.*

This suggested that ongoing professional learning and development in the pedagogical practices related to the STEM disciplines and in the knowledge, skills and dispositions of each of the STEM disciplines are critical to the successful implementation of high-quality STEM Education for all young Australians.

Although nine of the eleven participants selected Pivotal statement 1 (curriculum focus) to support their choice of vision it was not used to support the choice of Vision 2.

### 5.3.3 Question 3

*Any additional Comments*

Three participants provided comments.

Participant A:

> tried to accommodate both disciplinary and interdisciplinary perspectives … need clarity at the curriculum policy and the school level as to what really are the directions that should be embedded in the push for STEM, even if the way it is implemented may differ widely within and across schools. It will be interesting to see how it plays out …

This statement reflected the multiple approaches to the implementation of STEM education as identified in the literature review and the document analysis.

Participant D suggested:

> As professional educators, we should not live by acronyms alone, but endeavour to explain the philosophies behind them. Educational philosophies are alive and open to professional discussion and contestation about their underpinning assumptions and values. In contrast, acronyms (one-word slogans) appear to be cemented in place, especially when afforded official status by government and funded as special initiatives.

> … engage teachers in professional conversations about how the young people in their care (in loco parentis) should best be prepared to participate in rapidly changing working environments and in their local communities as socially responsible, well-informed and highly capable citizens.

This statement reminded educators to take care with the use of acronyms and to focus on educational philosophies that will promote professional discourse with teachers to provide the education young people require.

Participant P explained:

> More broadly, I'm not sure how useful STEM is proving to be as a term. … STEM is primarily about some vague, inter-disciplinary general skills and pedagogy and that it's more important than the content of its component disciplines. There is always support for this in education – it is similar to the 'inquiry method is all' approach in Humanities and Social Science of the 80's and 90's. This approach is wholly counter-productive to the goals of enhancing students' capabilities in Maths, Science, Engineering and Technology. The links across these disciplines are of course crucially important but of more importance is to articulate and explain the unique contribution to human understanding that comes from them, not having that washed away into some all-purpose, highly generalised statements about education and learning in the abstract.

Participant P, like Participant D, raised concerns about the use of the STEM acronym and emphasised the importance of building human capital through the development of an understanding of the STEM disciplines. This response articulated the political, economic and social nature of education.

### 5.3.4 Summary of the findings from Questionnaire 3

The participants as a group were focused on three components of STEM education. First was that knowledge, skills and understanding including decision making and solving issues or problems were integral components of STEM education. Second was that consideration must be given to exploring the local and global issues that are important to students now and those that may impact on their future. Third was that the participation of the community, individual governments, business and industry and education organisations was required to ensure the opportunities STEM education could provide were understood, particularly the employment and career opportunities in STEM and STEM related fields. Although this theme was not explicitly evident in the selection of the pivotal statements that underpinned most of the participants' choices of visions, it was not seen as contradictory. Rather it could be argued that it was inherent in the third pivotal statement that included the use of pedagogical

practices that would *inspire young people to choose STEM-related subjects at school and to pursue these into higher and/or further education and careers*. This was evident in the participants' conceptualisations of STEM education, as discussed previously. This suggested that the participants acknowledged that a political or economic agenda often underpins new initiatives and reforms like STEM education and that this presents opportunities that will be of benefit for young Australians.

Whilst Vision 3 was preferred by more participants than the other two visions combined, the pivotal statements supporting this choice varied. Some of these pivotal statements were also used to support the choice of the other visions. This suggested that if a single vision for STEM education in the Australian context was to be constructed it would need to accommodate individual conceptualisations of STEM education and varied approaches to its implementation if the intended outcomes of this vision were to be achieved. However, two pivotal statements were used to support the implementation of each of three visions. These were pivotal statement 3 which focussed on pedagogical practices and pivotal statement 4 which was focussed on the provision of professional learning for teachers. This also suggested the importance of ongoing professional learning in the content, skills and dispositions of each of the STEM disciplines. This is crucial to the successful implementation of the highest quality STEM education for all young Australians.

### 5.4 Conclusion to the Delphi study

The findings from the Delphi study represented the views of the selected participants at a particular point in time. The findings were not intended to be definitive but rather to provide examples of the opinions, ideas and understandings from a selection of participants with an interest in education in general and STEM education in particular in Australia. The application of the Delphi study provided a vehicle to elicit and explore the diverse conceptualisations of STEM education that exist within a community interested in understanding the challenges of STEM education in the Australian context.

This Delphi study showed that, although the participants as individuals have different conceptualisations of STEM education, there were shared similarities in its the purposes and requirements and an acceptance that a variety of approaches was suitable for its implementation. There was general agreement that STEM education should be part of the education program for all young Australians but exactly what this would or should look like was open to further discussion and debate. Issues and concerns related to the content,

assessment, intended or expected outcomes and the sustainability and evaluation of such an education program were raised.

Of the three visions presented to the participants, Vision 3*: STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they live now and into the future* was the most preferred. The pivotal statements selected to support this vision referenced the five themes identified in the document analysis. The same two pivotal statements relating to pedagogical practices and professional learning for teachers respectively were used by the participants to support the choice of all three visions. The participants irrespective of their choice of vision believed that STEM education would help young Australians manage their future in a challenging, changing and complex world.

At the time when the Delphi study and the semi-structured interviews were conducted interest in STEM education in Australia was significant and is likely to remain so for some time. The relationship between STEM education and the social, economic and political environment in Australia is likely to continue to unfold and develop.

In this study, the participants' conceptualisations of STEM education were found to equate to more than "just purpose plus requirements". As shown by the responses to the questions, the conceptualisation of STEM education is much broader and was dependent on the individual, their experiences, their personal and professional beliefs, the context for STEM education, who is driving it and the practicalities of policies and resources.

Although each conceptualisation was different and personal there were shared similarities in explanations, demonstrating that different conceptualisations are possible and that these can coexist in an environment focussed on achieving the best education for all young Australians. Understanding this will assist with the implementation of STEM education.

The Delphi study, like the literature review, suggested there is no one exact definition of STEM education. As nine participants' responses in the Delphi study showed, STEM education can be presented as an integrated, multidisciplinary or interdisciplinary approach to teaching knowledge and skills or solving real life issues that are relevant and engage students. Five participants from the Delphi study identified that it is the relevant and contemporary connections between the four disciplines of STEM that are important and that will matter to young people. Similarly, for seven participants from the Delphi study, STEM education is

about educating young people for future careers and employment that will require particular skills and knowledge and capacities. Three participants from the Delphi study suggested that STEM education will also equip young people to better manage their challenging and complex futures. Given that STEM is a short and catchy acronym, as suggested by several participants, it seems to have been given the weighty responsibility to drive future and sustained economic and social prosperity for all young people.

The following chapter will present and discuss the findings from the semi-structured interviews including how the participants saw their participation in this study. It will also explore particular responses to the questions asked in the Delphi study. The inclusion of a group of like participants who did not undertake the Delphi study enables an investigation and comparison of whether they shared similar opinions about STEM education in the Australian context, how they each conceptualised STEM education and the reasons for the vision they preferred.

# Chapter 6: Findings for the Semi-structured interviews

This chapter will present and discuss the findings from the semi-structured interviews with two groups of participants. One group had completed the Delphi study and the other group had not. The latter group of six participants are referred to as the Non-Delphi study participants. These participants were selected using the same selection criteria as that used to select the Delphi study participants. Both groups of participants were asked questions related to what can be learnt from past experiences in education reform and the likely future opportunities for STEM education in the Australian context. The Delphi study participants were given opportunities to further discuss and expand responses they provided on the three questionnaires from the Delphi study. The Non-Delphi study participants will also be asked to choose their preferred vision from the three developed in the Delphi study and to provide reasons for their choice. The list of questions asked of each Delphi study participant is included in Appendix 3. The list of questions asked of each Non-Delphi study participant is included in Appendix 4.

## 6.1 Analysis of the responses to the interview questions from the Delphi study participants.

### 6.1.1 Question 1:

*How would you like to be described as a participant in this research? (in 25 words or less)*

There were some shared descriptors evident in the responses to this question as shown in Table 6.1.

**Table 6.1 Shared descriptors in the responses to question 1 from the Delphi study participants**

| Descriptor | Participants |
|---|---|
| Science educator | A, B, D, F |
| Scientist | B, E |
| Social scientist | B, G, P |
| Industry experience | E, H |
| Mathematics educator | C, H, F |
| Teacher | A, F, L |
| Education researcher | A, B, C, D, G |
| Professional development (learning) for teachers | A, L |
| Teacher education | A, B, C, D, L |
| Leadership | B, G, P |

The participants described similar experiences leading to the shared descriptors shown in Table 6.1. There were also three distinct responses included in how the participants described themselves, which further illustrated the diversity of experiences of the participants. Participant E, with a background in the science and science research, suggested that preparing young people for employment in STEM and STEM related careers required a:

> broad background across all sciences which I think underpins the value of STEM education - because once you've got the principles of STEM education you can apply it to different content.

This response is an example of an *other* event as described by Webster and Mertova (2007: p.79) as it demonstrated how a personal belief is interwoven into the analysis of the importance of STEM education for Australia.

As evident in responses to questions from the second questionnaire of the Delphi study, Participant D continued to emphasise the importance of engaging students with their learning in meaningful and appropriate ways, so used the term *transformative educator* to explain why attention needs to be paid to:

> the past 50 years of educational research on how to engage students in transformational learning that addresses all levels of Maslow's hierarchy of needs, along a continuum that extends from the needs of the individual learner all the way out to the needs of Spaceship Earth.

In responding to question one, Participant H, like Participant E, took the opportunity to express a personal belief that focussed on the education programs in mathematics available for students and teachers and how mathematics could be made more attractive to school students. Participant H was:

> passionate about mathematics and education; and lack of 'good maths teachers trained in their discipline'; very concerned about decreasing numbers in school mathematics at intermediate and high levels.

The responses to Question 1 illustrated the shared and diverse experiences that the Delphi study participants were able to draw on in this study, leading to a variety of responses to the questions asked and producing a rich set of data.

### 6.1.2 Responses to the two questions related to the Delphi study

*Question 2: Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.*

No participant changed their opinions as a result of completing the Delphi study. However, Participants A, G, H and P agreed that it was interesting to read what others were saying or thinking in the information provided on Questionnaires 2 and 3. Participants A, C, H and P suggested that participating in the Delphi study helped them to clarify their understanding and to provide explicit examples of their views.

Participant A offered the following explanation as to why completing the Delphi study did not change their opinion and understanding of STEM education but was a useful tool in gathering and sharing information amongst participants and clarifying their position:

> I found it interesting, actually, when you put up those various positions. They're not positions I would have taken as pure positions … It made me very aware of some of the politics around STEM (education) … for instance, the economic rationalist … solidified my objection to seeing it in precisely those terms.

*Question 3: Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.*

Participant B, in critiquing the Delphi study suggested that questions relating to the factors that drove the introduction of STEM education, who or what benefited from the implementation of STEM education and who was encouraging others to do likewise, would have been useful:

> I think the thing that hasn't been explored is where did the idea of STEM come from? What were these social needs that generated—or political needs—that generated the sudden emergence of STEM from about 2007 onwards?

This is an example of an *other* event as described by Webster and Mertova (2007: p.79), where one participant has raised a question they believed was fundamental to understanding a particular issue, such as the introduction of STEM education, and, depending on how others responded, has the potential to become a *like* event. For example, the participants in this study who were responsible for the development of policies could have provided specific background information that explains why and how the policy was developed that would facilitate its successful implementation.

Similarly, Participant P believed that more attention should be focused on what it is that STEM education is expected to achieve and whether STEM education is understood in the same way by those with responsibility for its development:

> I think it's an area that requires greater clarity. I think it's become a catch all term and I think it's one of those terms that a variety of people can use it and they're not defining it or understanding it in the same way. So, I think that there is in any discussion around this, I think it's important to clarify, for the purpose of those discussions, what our basic understanding of it is. And I think the main dichotomy seems to me between a very generic understanding of what STEM is to be, some sort of process orientation, as opposed to a more fundamental approach to the importance of it as an area.

Participant C acknowledged the value and importance of professional conversations with colleagues to further develop their own understanding of STEM education and that the Delphi study was a beginning:

> What I'd really like to do is to have a conversation with the other participants and sort of, you know, get to hear their thoughts and the thinking through their particular contexts and everything like that. I think that would potentially have the effect of really maybe transforming my thinking in some way.

### 6.1.3 Responses to individual questions asked of the Delphi study participants

Each participant was asked at least one question related to their areas of expertise and the particular responses they provided in the Delphi study. The responses provided by each participant to their specific questions were diverse. Some shared themes emerged from the responses. A selection of the responses that illustrated these themes are included below.

In thinking about the acronym STEM (and STEM education generally), Participant A addressed assessment, accountability, pedagogy and by inference curriculum and explained "STEM becomes a handy way of talking about broad category of jobs that contribute to national wellbeing" and speculated "It's interesting isn't it, a little acronym, it's not bounded, is it?"

This response directed attention to the economic driver of STEM education which linked employment with national prosperity. The following response, also from Participant A, highlighted the need for meaningful learning and assessment that is relevant to young people's future within the environment of increased accountability for improved student outcomes. It also challenged educators to think about the type of assessment undertaken and how this is then used either to improve student learning or as a tool for selection into higher education or employment:

> We need to have better ways and valid ways of assessing kids' capabilities when they're doing real and rich tasks … a history of failure … I think because of the argument of reliability and selection …And so I think we need to rethink the way we do the this …think there's an increasing concern about the changing world of work and the kind of future that kids will go into … particularly in this environment of high stakes testing and global competition …

When thinking about and reflecting on the development and design of curriculum in Australia, Participant B framed science education as a necessary part of educating the whole person:

> I think we were strongly influenced by those notions of, that science education should be a contribution to the whole person learning. But we were defeated by two things; one was the structural thing that the national curriculum refused to change the idea of a ten plus two. And the second thing we were defeated by the federal nature of the powerful people, namely the managers of the different curricula coming from the states. We'd seen the same thing in ASEP* the model of science assessment was Year 12 … because assessment was the role of the states—we weren't allowed to create assessment examples to match what we were talking about.
>
> *ASEP was the Australian Science Education Program, for Years 7 to 10, developed from 1969 to 1974 and implemented across Australia until the late 1980s.

This response highlighted the complex and often tense relationship between the different government authorities responsible for education in Australia that existed in the past

and still persists today and its impact on the direction and implementation of any new initiatives or reforms in curriculum.

By drawing attention to past initiatives in curriculum reform, Participant B, like Participant A, focused attention on the importance of assessment that matches the curriculum initiative and is not bound to previous traditional or inappropriate assessment. Assessment can both prevent and encourage access and equity of access. Participant B continued:

> the assessment is very critically important. But it is an example of how you can change the assessment procedures to give much more influence on what is actually being taught, whatever the intentions of the curriculum are.

Participant C suggested that the delivery and implementation of STEM education:

> could be broadly integrated. But for things to be integrated they absolutely have to represent the connections between whatever the disciplines that exist within an integrated unit.

In this response, Participant C described an integrated approach or pedagogy for STEM education and suggested that the connections between the disciplines in the curriculum must be real, meaningful and relevant to the students and to the disciplines themselves. Unlike other descriptions of integrated STEM education, that of Participant C did not identify how many of the STEM disciplines had to be connected to produce integrated STEM education programs.

The connected and interconnected nature of the STEM disciplines was mentioned by other participants but was not always labelled as integrated. Those participants with a focus on secondary school STEM education were more likely to talk about connections and an interdisciplinary or multidisciplinary approach.

When discussing the community's relationship with STEM education, Participant E explained:

> I guess what I was thinking was around citizen science and what people do with their leisure time you know, there are some people who are great at sports and there are others who are good at something else. And then there's a whole bunch of people who are often searching for what it is, you know, what it is it that I can do with my spare time.

In this unique response, Participant E added another dimension to STEM education where it provides access and equity of access to leisure activities. This also suggested that

there are multiple contexts and purposes of STEM education that may better engage all students in their learning and their futures. It also suggested that STEM education could also occur outside the school at museums or art galleries or local parks.

Consistent with government initiatives including accountability practices that provide a place for anyone who wants to contribute to or be involved in STEM education, Participant E saw the development of initiatives as being of benefit to everyone:

> Yeah, I'd like to start with 'for all' and then if supplementary sort of programs were required that focus on a specific group.

Participant F highlighted the tensions within curriculum design regarding what is included and what is excluded and why and how the curriculum is presented and implemented. Participant F explained:

> Education is about meeting the needs of the student at that point in time. Not about this theoretical situation of what it's going to be like in the future but the here and now. The irony of that is … if you meet the here and now, if you help the student understand the concept at that point in time, that will actually lead to a richer situation down the track. So, the foundation that you have been able to build as a teacher with your students, in terms of their understanding, that in itself will be a good foundation for the future.

This response challenged the value of speculating about the future young Australians will face. In contrast, Participant F supported placing a greater emphasis on engaging students in deep learning where the application of knowledge and skills and understanding from the curriculum are front and centre, and address current issues with the possibility of these extending into the future.

Participant F also highlighted the role of assessment and linked it directly to the curriculum and to the pedagogy of teaching and learning:

> Assessment is unbelievably important. The whole purpose of teaching and the curriculum is to help people learn so we need to good measures of how we assess, how we determine if learning has occurred.

This response is an example of a *like* event as described by Webster and Mertova (2007: p.79) where one issue assessment, is broadened to include other areas such as curriculum and learning and becomes important to others, and so in turn may become a *critical* event.

Participant G suggested that there is:

> an exaggerated sense of the immediate vocational usefulness of STEM … not lots of jobs for scientists in Australia … it's a really important area people need to know about it … the jobs thing can be over-promised.

This response identified the tension between the need for a more STEM-trained workforce, for both specialists and technicians to ensure future economic prosperity as argued in government policies related to STEM education and the reality of the lack of jobs currently in Australia for highly qualified specialists. It sounded a cautionary note about expecting more from STEM education than what can be realistically delivered and accountability for reforms to education.

Participant H advocated that if "everybody did maths to Year 12 then the primary school teachers should have that level—a level—of mathematics to Year 12".

This response continued to illustrate Participant H's commitment to increasing access to quality mathematics education and the teaching and learning of mathematics. This response showed Participant H's positive belief that students are more than capable of studying mathematics at least to Year 12. Inherent in this response is the need for competent and confident teachers of mathematics, with exposure to ongoing professional development and learning and a high-quality mathematics curriculum.

Like other participants, Participant H also acknowledged that there were issues with approaches to STEM education that presented it as the grand solution to a list of problems. This also suggested that some sort of evaluation of what is being done or should be done and how outcomes are achieved and sustained was required. Participant E and Participant G shared similar opinions.

When considering if Humanities have a place in school education, Participant L provided the following emphatic response:

> Absolutely they do. We have a broad education and I believe that the current structure of the learning areas which include the humanities as well as the STEM disciplines is absolutely critical.

Participant P argued that STEM is often associated with the development of a set of generic skills that lead to a particular way of working that appears independent or disconnected from the knowledge, skills and dispositions of each of the discipline:

> some of the discourse about STEM is that it's just a way of working. I don't think it is just a way of working at all and I think the challenge is to understand and distil what it

> is that we want all students to have access to, particularly in the compulsory years, and how to do that well with discipline-specific methodology.

In taking this approach, Participant P argued that a focus on the content of STEM education programs alone ignored consideration of what other content should be included in the programs.

Participant P further argued that generic skills alone are not enough and that knowledge and context as presented in the curriculum are important components to building conceptual understanding. From Participant P's perspective, STEM education could be seen as more than skills, but what and whose knowledge and in what contexts it should be included, requires further debate.

When discussing the professional development required to support the implementation of STEM education, Participant P also suggested that although teachers have "some broad discipline- specific pedagogies", they do not always have the deep "subject specific knowledge that is required for curriculum development and developing resources."

When considering if Humanities have a place in school education, Participant L provided the following emphatic response:

> Absolutely they do. We have a broad education and I believe that the current structure of the learning areas which include the humanities as well as the STEM disciplines is absolutely critical.

The summary of the themes from analysis of the responses are shown in Table 6.2.

**Table 6.2 Shared themes from the individual questions asked of Delphi study participants**

| **Themes** | **Participant** |
|---|---|
| Curriculum- content, organisation | A, B, C, D, E, F, G, H, P |
| Assessment | A, B, F, G, H |
| Pedagogy- multiple approaches and delivery modes | A, B, C, E, G, H, P, L |
| Professional development/learning | A, D, E, H, P, L |
| Accountability | A, B, C, D, E, F, G, H, P, L |

The themes of curriculum content, assessment and pedagogy were consistent with three of the five themes from the document analysis. However, the themes of engagement of

students and access and equity of access were not explicitly included. If professional development and learning is seen as developing teachers' capacities to better interest and engage their students in STEM education, then the theme of engagement of students is implicitly included. Similarly, if accountability is seen to include providing access and equity of access to STEM education for all students in Australia regardless of their location, gender or ethnicity, this theme from the document analysis related to access is also included.

### 6.1.4 Responses to the question related to the provision of advice about STEM education

The three themes emerging from the responses are shown Table 6.3.

**Table 6.3: Summary of the advice for STEM education provided by the Delphi study participants**

| Advice for STEM education | Participants |
|---|---|
| Education programs included structure and organization, engagement of students and building strong foundations in the STEM disciplines | A, B, D, E, F, G, L, P |
| Professional learning and development included resourcing and accountability of teacher quality and training | A, B, E, H, L |
| Community included collaboration to increase participation in STEM subjects and provide jobs (careers and employment) | A, C, E, H, L, P |

The diversity of these responses is presented below. The following quote from Participant A was representative of the participants, who suggested that the focus of education and its purpose for today's students required attention:

> We need to change the way we look at knowledge, even, that we shouldn't think of it … I think we've just got to change that and start to think about, you know, how are we using education to prepare kids for independent and collaborative reasoning and thinking at a high level?

Participants E and H best captured the value and importance of STEM education, which was also a component of responses from other participants. STEM education was seen as being for all and would lead to an informed community with a good supply of technicians

and specialists, with expertise and passion and using their STEM knowledge and skills to solve problems and issues.

Participant E explained:

> I'm using the core principles of what I learnt through a STEM education every day in my current job …So it really is a life skill and that students need to follow their passion otherwise it can be self-defeating. So, there's no one size fits all but it's the general principles that set people up.

Participant H indicated that "STEM education is absolutely important to engage children, students, from early on through good teaching, through good communication with the community …".

This advice for STEM education reflected the themes from the document analysis of curriculum content, engagement of students and building strong foundations in the STEM disciplines, professional learning and development that introduces and refines pedagogical practices that enhance the quality of teaching, and access and equity of access, leading to increased student participation in the STEM disciplines.

The advice also reflected the focus on accountability and economic prosperity as expressed in government policies, for example, resourcing education programs, improving teacher quality and recruitment and the expectations of business, industry and the community in collaboration to provide employment opportunities, jobs and careers for all young Australians.

Participant L specifically discussed the importance of a vision that was developed in partnership with those working on the development of professional learning programs to support the implementation of STEM education. This piece of advice could be seen as an overarching goal underpinning STEM education in the Australian context, without which its successful implementation would be constrained. As such, is inclusive of the three pieces of advice listed in Table 6.3 above.

### 6.1.5 Responses to any other comments

Additional comments were provided by five participants, each of whom had a different focus. Participant C focused on access and equity of access for all students and recognised that whilst employment and future economic growth and prosperity are important, they are not the only function of education.

In addressing what Australian educators could do, Participant D believed that they should engage with and learn from their neighbours in Asia, as they share similar problems. Therefore, collaborating to find mutually acceptable and beneficial solutions at the regional, political and cultural level would be productive.

In reflecting on a long career in science and mathematics education, Participant F, whilst somewhat concerned about a possible negative impact of STEM education, offered hope that it is possible to deliver better outcomes for all young Australians through collaborative partnerships.

For Participant H, the importance of teaching as a valued profession should be acknowledged and promoted because it helps the learner to develop the knowledge and skills they need to understand their world and to evaluate and refine their ideas based on evidence.

The importance of building a literate community where all members have the tools to be actively involved in decision making was important for Participant P and was an example of a *like* event (Webster and Mertova, 2007: p.79), as it echoed responses from some other participants suggesting that it could become a critical event for others working in STEM education within a diverse community.

### 6.1.6 Summary of findings from the interviews with the Delphi study participants

Although the ten participants who completed both the Delphi study and the semi-structured interviews had experiences in common, they provided very different and often unique responses to the questions asked in the interviews. The responses reflected how they conceptualised STEM education and provided some possibilities and direction for its implementation and future. There were some common themes that ran through their responses. These themes drew attention to issues that had arisen with past initiatives that would likely impact on STEM education, such as the engagement of students, the relevance of the curriculum content to students' interests and needs and the pedagogical practices that support access and equity of access of all students. The provision of high-quality and ongoing professional development for teachers that fosters student excitement and creativity, has been and continues to be a critical component for the lasting success of any initiative or reform in education.

In this study, it was accepted that different opinions regarding STEM education in the Australian context would exist and that the participants' opinions may not change during or at the completion of the Delphi study. Five participants found it interesting to read what

others were thinking and four participants found that their participation in the Delphi study assisted them to clarify their ideas. This suggested that the Delphi study was a useful tool in capturing people's thinking and giving people an opportunity to articulate their thinking without the pressure to have everyone think the same.

Two participants provided specific comments regarding the questions used in the Delphi study. These comments reflected their stance in relation to STEM education and education in general. Similarly, two participants also provided comments relating to who was included in this study. Reflections on these comments are included in the next chapter.

When looking to the future, common themes pointed to the possible inclusion of new subjects to reflect developments in the respective STEM disciplines, the application of innovative assessment practices, presenting opportunities for students to face complex challenges and to thrive in a changing future, and the need to conduct honest and open conversations among all stakeholders about the future of education programs in Australia. To ensure the implementation of STEM education in the Australian context would require maintaining past successes in education reform as well as looking for new opportunities.

A specific response to advice about STEM education emphasised the importance of a coherent vision. This would ensure all stakeholders have a clarity of purpose, making it possible for them to work collaboratively to provide access and equity of access for all students to high-quality teaching and learning that engages them in STEM education programs now and into their future.

## 6.2 Analysis of the responses to the interview questions from the Non-Delphi Study Participants

### 6.2.1 Question 1

*How would you like to be described as a participant in this research? (in 25 words or less).*

There were some shared descriptors evident in the responses to this question as shown in Table 6.4.

**Table 6.4 Shared descriptors in the responses to Question 1 from the Non-Delphi study participants**

| Descriptor | Participants |
|---|---|
| STEM Educator | R |
| STEM background | S, T |
| Research scientist | T |
| Education Researcher | R, X, Y |
| Teacher | M, Y |
| Leadership | X, Y |
| Educator pre-service teachers | M, R |
| Policy | R, S |

The participants described similar experiences, leading to the shared descriptors shown in Table 6.4. There were also two distinct responses which illustrated the diversity of experiences of the participants. Participant T, a biomedical research scientist, suggested that they had "enjoyed the benefits and the stimulation of learning in the STEM area throughout my career". Participant Y indicated that being a teacher was central, shaped their leadership in education and informed their continuing commitment to STEM education:

> I would start as a Chemistry teacher, first and foremost. Secondly, as an educational leader, committed to STEM education, particularly for girls. Thirdly as being involved in the philanthropic sector.

### 6.2.2 Question 2

*Why do you think 'STEM education' is gaining so much attention now?*

There were shared reasons in responses to this question as shown in Table 6.5.

**Table 6.5 Shared responses to Question 2 from Non-Delphi study participants**

| Reason | Participant |
|---|---|
| Stakeholders with a shared responsibility for STEM education included governments, public, schools, business, industry, universities and TAFEs and the community. | R, S, T, X, Y |
| Education included engagement and participation of all students, making connections between the STEM disciplines and increased performance on national/global tests. | M, R, S, T, X, Y |
| Securing the future economic growth and prosperity to respond to a challenging future with new jobs that require new knowledge and skills. | M, S, T, X |

Examples that were illustrative of the participants' responses to this question are included below.

Participant R indicated the importance of communication between all involved in STEM education so that education has an equally strong voice in any discussion or debate related to its development, implementation and evaluation. They also sounded a note of concern or alarm:

> STEM education … I think that's interesting, because we're interested in it from a STEM education perspective, but when you often hear about government talking about STEM it's about STEM; STEM which is about scientists, technologists, those people who are actually doing research in those areas and I have the utmost respect for those people, but they are not STEM educators.

In contrast, Participant X focussed on the economic driver of STEM education and acknowledged the influence that the changing nature of the economy at the community, national and global levels have had on the direction and nature of education:

> I think it's basically come out of the changing economy, global changing economy. That the manufacturing for Western countries has completely dropped, they've looked where the job markets are, they've looked at the examples of the high-tech companies that are making all the money now and so I think it's a genuine concern on the behalf of- let's just say OECD, Western governments—to make sure that their economies thrive and identifying that it's really technology is driving a lot of those things. And when you look at the companies that are really thriving, and the sort of industries, and, so … that's where I think ... that's where the STEM agenda is—has come from.

Lastly, Participant Y placed an emphasis on the needs of society - "I think society needs a higher level of STEM education than in the past … and we're not engaging them (students)

at the younger years. So, I think it's, it's reached a tipping point and … society has become much more complex".

In this response, Participant Y highlighted that when introducing new initiatives attention needs to be paid to what currently exists and how this might impact on or influence the implementation of the initiatives. Introducing the need for more people in STEM related careers and employment and engaging more students in the STEM disciplines at a time when the number of student enrolments in STEM related studies at the post compulsory level of schooling and the tertiary level continues to decline may introduce other problems (e.g. student perception of the difficulty of particular STEM subjects) that need to be addressed. This response was a further example of a *critical* event (Webster and Mertova, 2007: p.79) and a significant event (Daiute 2014) as it had the potential to impact on all interested in about STEM education.

### 6.2.3 Responses to individual questions

Each participant was asked at least one question related to their expertise and experiences. The responses provided by each participant to their specific questions were unique and diverse, but some shared ideas emerged as shown in Table 6.6.

**Table 6.6 Shared themes from the individual questions asked of the Non-Delphi study participants**

| **Themes** | **Participant** |
|---|---|
| Integrated or discipline approach to implementation of STEM education | M, X |
| Equity of access (for all students) to high-quality teaching and learning | R, X, Y |
| Professional development programs for pre-service teachers and teachers | M, R, S, X |
| Partnerships between all stakeholders with an interest in STEM education | S, T |
| Evaluation of and accountability for resources to support STEM education | T, Y |

In support of professional development programs, Participant M strongly advocated for ongoing professional development for pre-service teachers, classroom teachers and school leaders, that addressed both how and when to best use technology with students. Participant

M also defined technology as consisting of both design processes and digital processes. Professional development would include ensuring teachers were able to identify and understand how technology, from the both design and digital process perspective, is best suited to support student learning and how to effectively manage this technology. In support of an integrated approach to STEM education in the primary years of schooling, Participant M also argued that like the other STEM disciplines, there was a knowledge and a disposition as well as a skills component of Technology. Participant M also strongly supported the inclusion of technology across the curriculum.

In responding to questions related to student access to and participation in STEM and STEM related subjects, courses and employment, Participant R identified the complex issues associated with education and suggested why STEM education is sometimes seen as an easy solution for these issues. Participant R explained that the differences between the rates of participation, retention and achievement levels in the STEM disciplines or subjects for females and males are not uniform. Biomedical and biomedical engineering are attracting and retaining females and more females than males are enrolled in senior secondary psychology and biology subjects. In discussing the evaluation of policies and programs in STEM education, Participant R lamented the lack of reference to past research that identified the factors that influence students' subject choice and showed concern with the use of convenient acronyms and with what STEM education actually is and is reasonably expected to achieve. In supporting professional development for teachers, Participant R argued that it should move teachers beyond pedagogy and into considering how the whole curriculum was designed, constructed and implemented. Consequently, Participant R strongly advocated that good practices in teaching STEM education are good practices in teaching and applicable for all students and to all disciplines.

As a participant who did not have a specific education background, Participant S demonstrated a knowledge and an awareness of issues that are currently being discussed in schools. Participant S expressed a particular concern about the workload for teachers and how adding STEM education without subtracting anything else from school programs would impact on its effective implementation. In advocating for sustainable partnerships between business, industries, universities and schools to address the issues related to the development and implementation of STEM education, Participant S supported a "hasten slowly" approach to build collaboration and achieve agreed outcomes for students. Participant S further explained that it was acceptable if some funded initiatives for STEM education *failed* to

deliver the expected outcomes, provided the failure was regarded as an opportunity to learn and subsequent learning was transferred to other education programs.

In support of both a discipline and integrated approach to STEM education, Participant T connected the approach to research in science with the design process from Technology and Engineering, where designs change in response to *failures* of the prototypes leading to better or improved products. This was similar to the approach of Participant S. This is an example of an *other* event (Webster and Mertova, 2007: p.79), where the opinion of one participant is similar to that of another participant but could become a *like* event if other participants shared similar opinions.

Participant T also highlighted the interaction between research and policy and how this has impacted on the type of research funded. Taking a business and economic approach to the evaluation of research proposals, Participant T suggested this may lead to newer or different approaches to research funding with an emphasis on national and international collaboration and partnerships. Such an approach may also support the development and implementation of STEM education.

Like Participant T, Participant X also raised concerns as to the nature of Technology as digital or design or both and the relationship between Mathematics and Technology in particular. Participant X pointed to possible future directions for mathematics teaching and pre-service teacher education in mathematics where there was a focus on building an understanding of the knowledge required by particular STEM disciplines and how this would lead to real connections between the disciplines. Participant X was supportive of professional development programs for all teachers and a review of curriculum and associated pedagogical practices and argued that a stronger focus on abstract thinking would link the disciplines to a specific general capability (e.g. critical and creative thinking) from the Australian Curriculum or from the list of twenty-first century skills. Participant X also suggested Mathematics was the discipline that supported the development of and was applicable to other disciplines.

As a member of a philanthropic organisation that supported education, Participant Y identified three challenges for such organisations. First was in deciding how to effectively allocate resources, particularly funding so that the selected projects deliver outcomes, for example the development of new resources for STEM education. In particular, Participant Y was keen to support regional and rural schools to submit proposals and to participate in

projects. Second was in ensuring the funded projects were evaluated using evidence, as supported by Participants T and S, including acknowledgment of successes and learning from any failures. Third was in forming partnerships with schools and other groups, for example between universities and business to enhance and disseminate outcomes and findings and to conduct and publish research. Participant Y argued that this would assist with defraying costs, making it possible to increase participation and reach more schools and students. Underpinning these challenges is accountability and the importance of evaluation as evidence of accountability.

### 6.2.4 Which is your preferred vision?

*Which of these visions is your preferred vision (best matches/aligns with yours)? Please elaborate. Do the purposes you have for STEM education fit with the vision?*

Each participant selected a preferred vision from the three developed from the Delphi study as shown in Table 6.7.

**Table 6.7 Preferred choice of Vision by the Non-Delphi study participants**

| **Vision** | **Preferred by Participant** |
|---|---|
| Vision 1: *STEM education contributes to a broad suite of learning experiences that enable all young people to participate in and contribute to building sustainable communities.* | M |
| Vision 2: *STEM education provides the skills that enable all young people to contribute to growing the nation's economy and global competitiveness.* | X |
| Vision 3: *STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they live now and into the future.* | R, S, T, Y |

In selecting Vision 1, Participant M believed that STEM education should be relevant to the community in local and global contexts and that learning be accessible to and supportive of all young people, enabling them to participate and contribute:

> In the end we do have to worry about the nation's economy and global competitiveness and the nature of the world that we live in and all of that but initially I think it's important that students participate in it and learn how to use it as part of the learning community that they're in.

In selecting Vision 3, Participant R included STEM education as part of a liberal education that includes thinking processes and the development of knowledge and skills. This would then support all young people to manage a complex and challenging future. Participant R explained that students should be:

> able to move and change in a world that is complex, is constantly changing and there are going to be challenges and I think it's important for everyone. Not a small group, not a whatever or whatever, and I think that … STEM education can do that, but I don't think STEM education does that on its own … added the thinking processes so it's knowledge, skills.

In selecting Vision 3, Participant S, like Participant R, believed that STEM education was making a positive contribution as it equips all young people to understand the fluid, challenging and changing nature of the global community. Participant S also acknowledged that how STEM education is conceptualised is very much dependent on the individual and that colleagues may have chosen a different vision. They further suggested that "there is a need to conceptualise STEM education before implementation and this vision is about the how rather than the what and is agile …".

In selecting Vision 3, Participant T, consistent with Participants R and S, presented STEM education as the provision of knowledge and building understanding to meet a changing and challenging nature of the future and:

> to make informed and rational decisions people should have a good or basic understanding of the sort of complex challenges we're facing rather than being influenced by whatever the media or the political or economic voices that they're getting air.

Participant T also strongly supported an inclusive STEM education because "I think STEM hopefully should be reaching out to, not only the young people, but everyone in society". Participant T also reflected on what the other two visions offered and suggested that Vision 2 was too narrow but whilst economic prosperity matters it should not be the highest priority and Vision 1 was not strong enough to achieve the intended outcomes for STEM education.

In selecting Vision 2, Participant X described STEM education as being an economic construct, where skills are required by all young people to deliver the political agenda of continuing growth and prosperity nationally and globally. Although Participant M gave a similar reason, they chose Vision 1. In selecting Vision 2, Participant X acknowledged that it

was a personal one and expressed concerns about how much mathematics is *actually* included in STEM education:

> Now, science and maths education in schools should be more than just that agenda... you need to meet that agenda … probably in the interests of many students that schools meet that agenda really quite well. And certainly, STEM education is not the whole of education.

In selecting Vision 3, Participant Y, like Participants R, S, and T, presented STEM education as the provision of the relevant and real knowledge and skills young people need to understand the world and its future:

> STEM is everywhere and to be a fully functioning, involved and contributing citizen you need to understand and comprehend the impact of STEM. Bonus would be an increase in career options and increase contribute to Australia's economic development.

From these responses four shared reasons as to why participants chose a particular vision emerged. These are shown in Table 6.8.

**Table 6.8 Reasons for choice of preferred vision by the Non-Delphi study participants**

| Vision | Reasons for choice | Participant |
|---|---|---|
| 1 | Economic growth and prosperity and<br>Access for all to real and relevant knowledge, skills and understanding. | M |
| 2 | Economic growth and prosperity and<br>Contribute to the community. | X |
| 3 | Economic growth and prosperity<br>Manage future (complex, challenging, changing)<br>Contribute to the community<br>Access for all to real and relevant knowledge, skills and understanding. | S<br>R, S, T, Y<br>S<br>R, Y |

### 6.2.5 Conceptualisations of STEM education by the Non-Delphi study participants

The analysis of the reasons as to why the participants chose a particular vision and their responses to the previous questions were used to construct the following conceptualisations of STEM education for the Non-Delphi study participants.

Participant M presented STEM education as a way of connecting students to their world and to foster their interests using an integrated approach with real links and connections between subjects. Participant M considered that for STEM subjects "the subjects would be treated equally, and they would be merged together and there would be interactions between them."

Participant R described STEM education as including knowledge, skills and thinking processes with a focus on the changing complex world now and in the future and as a part of the whole education of young people:

> It's about building their knowledge and understanding and thought process … so that they're independent learners, which means that they are able to move and change in a world that is complex, is constantly changing and there are going to be challenges and I think it's important for everyone.

Participant S presented STEM education as a way of approaching and solving problems that requires knowledge, skills and understandings from across the four STEM disciplines:

> building STEM literacy and by that it's more around the 'how' rather than the 'what'. The subjects are the 'what', the 'how' is the skills that are developed such as critical thinking, design thinking, the synthesising of a huge amount of information and determining what's the right or what the facts are.

Participant T believed that STEM education provides broad and specific experiences that support people to assess important decisions made by governments in response to new and future challenges that will matter to people:

> By getting exposure to STEM, (people) would be able to judge important decisions by themselves, by their local government, by their national government, by global leaders, on the future of the world … from the mini scale to the really macro scale, more readily.

In referencing the changing nature of work, Participant T also offered a picture of what interdisciplinary and collaborative approaches could look like where:

> Science brings scientific method plus specific discipline knowledge; Maths builds understanding and skills in using quantitative methods and conceptual thinking; Interdisciplinary and collaborative approaches.

Participant X saw STEM education as responding to the changing economy locally and globally where a specifically trained workforce is required to meet the challenges in a real-world context because "STEM is obviously really, really important but it's the economics."

Participant Y identified STEM education as both generalist and specialist in nature and leading to informed citizens, able to make decisions and reflect on how their world has changed and continues to change:

> Society needs a higher level of STEM education than in the past … You don't have to be an experienced STEM person, but you need a bit of basic understanding think to be an active citizen, you require a good understanding of STEM.

Similarities in the participants' conceptualisation of STEM education were observed. Participants M and R supported an approach that drew knowledge, skills and understanding from across the four disciplines of STEM. Participants R and S highlighted the need to include the development of thinking processes as part of the education for young Australians. In addition, Participants T and Y linked STEM education to building the capacities of citizens to make informed decisions related to their futures. However, Participant X's conceptualisation of STEM education with its focus on the economy was contrary to those of the other participants.

### 6.2.6 Responses to questions related to Advice for STEM education

*From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?*

Although the participants had different experiences and positions their responses to this question contained some shared themes as shown in Table 6.9.

**Table 6.9 Shared themes from the advice for STEM education provided by the Non-Delphi study participants**

| Themes | Participant |
|---|---|
| Focus on students and their learning providing solid foundations including both depth and breadth and, thinking processes | R, S, T, Y |
| Equip more people in the community with knowledge and skills to make informed decision or question decisions | R, S, T, Y |
| Interconnected, cross curricula, shared and real overlap (not trivial) between the STEM disciplines | M, S, X, Y |

Generally, the advice provided supported the role of STEM education in building an informed community capable of making decisions about their futures. There was also a focus on the development of skills as well as knowledge and the connections between the

disciplines. The following responses from Participants M and T illustrated these similarities, with Participant M offering:

> My concern is that one of them is in the centre and directs the others. I think they should be overlapping in a Venn diagram and not just overlapping but seriously overlapping in the centre (showing) learners that there are links between the subjects.

and Participant T suggesting:

> if you learn that process of being able to evaluate facts and arguments and so on, and if that comes to you through learning the method of science and scientific research and so on, then that's going to stand you in very good stead for your entire life …you'll be able to weigh up what the media's saying, what the politicians are saying, what the world leaders are saying …

However, there were also three different pieces of advice provided. Participants R and S shared the belief that STEM education is empowering and of benefit for all, although the contexts for the responses differed, with Participant R focussed on informed citizens and Participant S focussed on the connection between economic prosperity and technology. Participant R advised that STEM education was necessary for all:

> To be our thinkers and to be our decision makers in the future, and I'm not talking about decision makers at a political level, or whatever, but I'm talking about as parents, as citizens, as voting people with voting rights.

and Participant S explained that "everyone benefits from thriving economy and STEM underpinned technology advances."

Participant X believed that there is some uncertainty as to the role and place of mathematics in STEM education and argued that "Maths people have to take its inclusion in STEM (education) seriously."

This response suggested that the role and place of mathematics in STEM education required further exploration. This response is an example of a *critical* event (Webster and Mertova, 2007: p.79) and a significant event (Daiute, 2014), where the introduction of a new initiative like STEM education has impacted on the participant and how their colleagues are or are not engaging with this initiative. It also hints that there may be consequences for the discipline of Mathematics if it does not become an active participant in STEM education.

Participant Y pointed to the current debates about the place of design and the design process in technology and engineering and how this is related to The Arts and what should be

included and excluded from STEM education. Participant Y then proposed that we “change the name and suggested STEAM brings in design critical to future”.

### 6.2.7 Responses to questions related to the longevity and impact of STEM education

*Will STEM education be around 5 or 10 years? Why? If not, what will have replaced it?*

The participants were generally unsure if STEM education would still be a focus in five or ten years and if not, what may have replaced it. Some responses suggested that if STEM Education was still seen as important then it would most likely remain a focus of education for young people. These responses also included the views that STEM education would have evolved but what this would look like was unclear, and that a new acronym may have emerged that was more inclusive of future citizenship or that perhaps education may not be using any new acronyms.

Given this uncertainty amongst the participants a follow up question was asked. This question was: *What do you believe could be the likely or lasting impact or legacy of STEM education?*

It was thought that in responding to this question the participants may point to what they thought may replace STEM education.

Six likely or lasting impacts were inferred from the responses to this question and are shown in Table 6.10.

**Table 6.10 Likely lasting impact on STEM education by the Non-Delphi study participants**

| Likely impact of STEM education | Participant |
|---|---|
| Cognitively engaged students, applying their learning seamlessly | M, R |
| STEM education seamlessly included as part of the curriculum not as a replacement for the disciplines | R, X |
| STEM education as an enabler not just another initiative and contributing to growing the economy | S, X |
| Greater stakeholder engagement through partnerships in education and increased resources | S, Y |
| Part of a balanced or liberal education which includes the Humanities and the Arts | M, Y |
| Although the problems being faced might be different still will need STEM knowledge and skills, innovation and thinking processes to solve these | M, R, S, T |

There were some shared responses between the participants. Participants M, R and S, when discussing student engagement focussed on providing reasons for what was included in STEM education programs. Participant M suggested "for our younger students … we need to be thinking about 2025 or 2030". In addition, Participants R and Y suggested that the following question also should be asked "What is the benefit (of STEM education) to your students now and into the future?".

There were also three distinctly different comments provided by Participant S, Participant T and Participant Y. Participant S suggested that taking the bigger picture view of STEM education is important to ensure progress and that where the ongoing evaluation suggested the modification of stated outcomes is done and explained:

> I think one of the things worth investigating as part of this research is this emerging approach developmental evaluation, which is really that whole kind of agile framework again, not locking into outcomes or impact that may change over time, but being adaptive and looking at how to evolve that … not letting perfection get in the way of progress, and setting up these measures and say, oh well we're not hitting those, but losing sight of the bigger picture.

Participant T sought to show the reach and the value of STEM education beyond that of just an economic driver of prosperity because "STEM education has interaction with all aspects of life not just work…".

Participant Y provided insight as to how difficult it can be to predict the next big issue in education. Participant Y, like Participant S, suggested that making a fixed time commitment including ongoing review to an initiative is critical for its successful implementation:

> There are many competing hats in education as to what's most critical and, you know, there's a guess that maybe welfare will be one of the more important issues in five, ten years, if we make a difference in Science, Technology, Engineering, Art and … Technology.

### 6.2.8 Responses related to the opportunities for STEM education

*If STEM education is (or is to be) the answer, what is the question? If it is not the answer then what should the question be?*

The responses to this question were diverse and reflected each participant's conceptualisation of STEM education. There were some common threads evident in the responses. This was illustrated in the following four responses.

Participant M offered "I think if we think STEM is the answer, then to me that's a problem. STEM education doesn't go far enough."

Participant R commented that "teachers are focused on Oh we need to do this; we need to do that well why? Why is that of benefit to your students now?".

Participant X suggested that "STEM education is a part of the answer to- What is the education required for young Australians?".

Participant Y believed: "STEM is part of the answer, in that quality STEM education is part of what's lacking in contemporary education".

These four responses suggested that there is a general acceptance of the inclusion of STEM education in the education programs offered to all Australian students. However, these responses also suggested that discussions related to STEM education should be part of a larger discussion that focusses on the whole education program provided to all young people in Australia.

The alternative questions to which STEM education could be the answer suggested by Participants M, R, T and Y were very similar. These too focussed on looking at the education provided to all young Australians as a whole, of which STEM education was one component.

Participant S was concerned with sharing best practices across Australia to ensure all students benefit from high-quality STEM education programs. The question was seen as focussing attention on how to support equity of access to STEM education regardless of location, gender or culture.

Also, Participant X maintained a focus on the relationship between STEM education and economic growth and prosperity. Their question was designed to focus attention on what was required to support social cohesion and inclusion through economic prosperity.

### 6.2.9 Responses to any other comments

Five participants provided additional comments. These comments were a mix of positive and negative statements and reflected their concerns for and about STEM education. Participant M was concerned with the acronym itself and questioned if it truly supported connectedness between learning areas. Participant R was concerned with the continuing focus on the economic and political agenda of STEM education and the impact this has had on educators, especially teachers, as they seek to provide what their students need for their future. Participant T supported an integrated approach to education and the importance of STEM education and its role in providing a balanced life. Participant X, like Participant T, wanted governments to better promote STEM education and to emphasise its impact on people's lives. Participant Y expressed concern about the effective use of limited resources and identifying where the greatest impact can be made.

### 6.2.10 Summary of the findings from the interviews with the Non-Delphi study participants

The participants' responses were diverse as to what question STEM education was the answer to and what alternative questions should be asked. However, each participant pointed to the need to focus on the benefits of STEM education for young people including increasing their engagement with learning. These responses also presented STEM education as being a component of the education that is offered to students at least in the compulsory years of schooling. Equally important was the emphasis the participants placed on educating young people to become informed citizens, who contribute to their community and are able to make decisions about issues that matter.

One vision, Vision 3: *STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they*

*live now and into the future* was the preferred choice for a vision of STEM education in the Australian context by four of the six participants. Vision 1 was preferred by one participant. Vision 2 was also preferred by one participant. The reasons provided by participants to support their choice of preferred vision referenced economic growth and prosperity, access for all to the relevant knowledge, skills and understanding, contributing to the community and managing the future. These reasons were different from those provided by the Delphi study participants. If relevant knowledge, skills and understanding were seen as relating to curriculum and access for all related to the use of appropriate pedagogical practices to engage all students, then this reason would equate to two of the most chosen reasons provided by the Delphi study participants. If professional learning for teachers related to the provision of relevant knowledge, skills and understanding, then this reason would also equate to one of the other the most chosen reasons provided by the Delphi study participants.

The Non-Delphi participants used the same reason, economic growth and prosperity, to support the choice of different visions. The other three reasons could be seen as integral to and an outcome of achieving economic growth and prosperity. The use of the same reason to support the choice of each vision was similar to that in the Delphi study. The difference was that in the Delphi study, the two reasons provided had a focus on pedagogical practices and ongoing professional development of educators.

When looking to the future for STEM education, the responses from the participants were mixed. In general, they supported its inclusion in education programs for young Australians. However, not all participants agreed as to what the STEM education programs should look like. They did agree that the provision of high-quality and ongoing professional development for teachers was essential to ensure the best outcomes for all students. All participants were supportive of a professional discourse that considered what education for young Australians should look like.

Several participants identified the need to challenge the same old approach to education, for example, specific content for each year level or external examinations to curriculum design and assessment practices. They suggested that it was time to try something new or different, such as open-ended inquiries to develop understanding of concepts or using oral presentations for assessment. They also commented, that if new approaches didn't work as expected, then it was important to find out why and to make any necessary changes and improvements. Rather than seeing failure as a negative, it should be seen as an opportunity to learn and to build something better suited to delivering the desired outcomes.

Each participant suggested an alternative question. Although the alternative questions suggested by the participants were different, each had a forward-looking focus, pointing towards understanding what future education for all young Australians would or should like. However, decisions will be required as to the structure and content of the education programs, which pedagogical and assessment practices should be used, the recruitment of highly qualified teachers and an accountability framework to ensure the expected outcomes have been achieved. This in turn raises questions about who should be included in discussions about what the future education of young Australians should look like and who would lead these discussions. Put simply - who should decide what is the best education program for young Australians now and for their futures?

Similar to the Delphi study participants, four of the themes from the document analysis were reflected in the conceptualisations of the STEM education of the Non-Delphi study participants. The theme of assessment was inferred in building understanding across the STEM disciplines and using this to solve problems.

### 6.3 Discussion of responses to the interview questions from all participants

The responses to the interview questions reflected the diversity of opinions, ideas and experiences of the participants. Within this diversity, similarities were observed between participants A, B, C, D, E, F, G, H, L and P who had completed the Delphi study prior to their interviews and the Non-Delphi participants: M, R, S, T, X and Y. This was illustrated in the participants' responses to the first question asked in each interview. When discussing how they would like to be described in this study, there were five descriptors shared across both groups of participants. These were education researcher, teacher, scientist, teacher educator (including for pre-service teachers and professional development for practising teachers or in a specific STEM discipline) and leadership experience. All but one participant aligned with at least one of these. There were two descriptors unique to the Delphi study participants: social scientist and industry experience. It could be argued that research could be seen as a component of the role of a social scientist and industry experience, suggesting that if a broad descriptor of research was used then almost all participants in the study would be researchers. There were three descriptors unique to the Non-Delphi study participants: STEM educator, STEM background and policy. It could be argued that policy (development and implementation) could be associated with leadership experience. If this was accepted, then the participant from the Non-Delphi study who had not previously aligned with the other

sixteen participants was now aligned with the leadership experience descriptor. Reflections on the STEM educator and STEM background descriptors are included in the next chapter.

When focussing on the emergence and purpose of STEM education, Participants B, F and R sounded a note of concern about who was driving the implementation of STEM education, what evidence was being using to support it and what it could reasonably be expected to achieve. Likewise, Participants A, M and P expressed concerns about the acronym STEM itself and its use. They asked whether it was a popular catch phrase for use in policies or a meaningful term that would impact positively on the education of young people in Australia.

Both Participants H and X focussed on economics, continued growth, social prosperity and being globally competitive as the drivers for STEM education. This was similar to Participants E, L and Y, who also included an emphasis on the needs of society as an important driver for STEM education.

For Participants B, C, M, and S, STEM education provided opportunities for primary schools to develop and implement integrated programs that brought together the STEM disciplines.

Participants A, F, G, H and X suggested that some foundational knowledge in mathematics and the sciences was required as part of STEM education. They further explained that some of this content could be delivered in different contexts, as was most applicable to implement STEM education programs to different cohorts of students across Australia.

Overall, four themes relating to the implementation of STEM education were shared between the Delphi study and Non-Delphi study participants. These were:

- accountability including evaluation which was included by twelve participants;
- pedagogy most relevant to the students' interest and needs which was included by ten participants.
- curriculum (content and organisation) which was included by nine participants;
- professional development and learning which was included by eight participants.

In addition, the theme of assessment was only included by five Delphi study participants. Two themes were only included by the Non-Delphi study participants. These

were equity of access for all students to high-quality teaching and learning, and partnerships between all stakeholders with interests in STEM education.

Each group of participants expressed their advice for STEM education differently. The Delphi study participants provided advice in three broad areas. These were related to the structure and content of STEM education programs, professional learning and development for teachers, and community participation.

The Non-Delphi study participants also provided advice in three areas. One of these was similar to that provided by the Delphi study participants. This was the interconnected and cross curricula approach to the STEM disciplines with shared and real connections between these disciplines. This was relevant to the structure and content of STEM education programs. The two different areas of advice included a focus on breadth and depth of learning required to build solid foundations in the STEM disciplines with the inclusion of thinking processes, and equipping more people in the community with knowledge and skills to make informed decisions or to question decisions.

Both groups of participants referenced including the community in STEM education programs. If professional learning and development for teachers was seen as integral to supporting student learning, then the advice from both groups was very similar.

In providing directions for the next steps for STEM education, all the participants focussed on providing learning that engaged all young people because it was relevant to them now and would be into their future and also showed the real and deep interconnections between the disciplines of STEM. This captured what the participants regarded as the strengths of STEM education. The following three comments were representative of those from all participants.

Participant F reminded us focus on the now as well as the future:

> And by that it means that the learning has to be relevant in them solving their immediate problems as they live, as then their future problems as they grow as adults…statistical methodology is a much more powerful tool and that's something which we haven't really focused in on as much as we should in our maths curriculum.

Participant P provided a way to get people to buy in and support STEM education because it matters to all young people:

> The community understanding and commitment … is quite different. And if we can harness this conversation about STEM to unpick down to that very basic level about

> what it means … why it's important to be numerate in your life, regardless of whether you're going to be an actuary or a financial whizz kid or a rocket scientist, just to be an active citizen.

Participant Y, by focussed on the quality and contemporary nature of STEM education programs:

> What is the best education that we could provide today for a young person who's going to see the turn of the next century?' So, the first question is: 'What should be in it?' And the second question is then: 'What is missing or lacking from today's education to make it that?' And STEM is part of the answer in that, quality STEM education is part of what's lacking in contemporary education.

Two additional issues were raised by some participants that were not directly addressed in this research but are worthy of further investigation and consideration. Participants F, M, S and T specifically queried whether STEM education was being added to what they saw as an already overcrowded curriculum and the impact this would likely have on the quality of teaching and learning and the engagement of students with the education offered to them.

Participants F, M and P also questioned what exactly was meant and understood by the inclusion of the T in STEM education: Does it mean design, digital and processes, all three or something else?

Four participants suggested that industry was one of the drivers for the current attention on STEM education. They suggested this led to connecting economic growth and social prosperity with the engagement and participation of all students in STEM subjects and courses, leading to a community that understood the importance of STEM education and a suitably skilled future workforce.

Although the final comments provided by the participants were diverse, these were underpinned by a concern for the education provided to all young Australians and provided both direction and hope for the future of education. It was suggested that best practices in STEM education programs be shared across Australia to support access and equity of access for all students. The participants also believed that if all those involved in education have a clarity of purpose and work collaboratively, it would be possible to provide the access and equity of access for all students to high-quality teaching and learning that engages students in STEM education now and into the future.

### 6.4 Conclusion to the semi-structured interviews

Although the responses to the questions asked in the semi-structured interviews provided a diversity of opinions, there were some shared ideas and beliefs as to why STEM education has gained importance, who is driving its implementation and what it could realistically be expected to deliver when properly resourced. The participants were generally positive about STEM education but were prepared to express reservations about its likely achievements, longevity and sustainability.

In general, the participants suggested that the implementation of STEM education goes beyond preparing young Australians for employment. It also provided opportunities to address the issues of engagement of students and their access and equity of access to a high-quality education. STEM education was seen also as offering opportunities to provide better outcomes for all students and to enable them to make informed decisions about their futures.

Of the visions identified from the Delphi study, Vision 3: *STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they live now and into the future,* was the preferred choice by eleven of the seventeen participants in this study (seven Delphi study participants and four Non-Delphi study participants). The reasons given to support this choice of vision were different across the two groups of participants. In their interviews, the Non-Delphi study participants gave only one reason to support the choice of different visions. This was economic growth and prosperity. In the Delphi study, the same two reasons were used to support the choice of different visions. These were related to pedagogical practices and the provision of ongoing professional learning for teachers.

In the responses to the semi-structured interviews, the participants addressed in varying degrees the same five themes of engagement of students, access and equity of access, curriculum content, pedagogy and assessment that emerged from the document analysis. In considering the provision of high-quality education for all young Australians, Participant P best captured the sentiments of all participants when suggesting that an informed member of the community when presented with new things that they can't understand should be sufficiently resilient and confident to realise:

> You can do something about it, you're not stuck with this idea that I either get it or I don't. I think that's a real stumbling block. But broadly speaking is that there is a community narrative that understands that it is important that everyone becomes literate, and two, you can do something about it … active and empowered citizen and consumer.

The next chapter will bring together the findings from the document analysis, the Delphi study and the semi-structured interviews undertaken in this study to discuss the implications for STEM education in the Australian context and to consider the challenges it faces.

# Chapter 7: Discussion and Conclusion

This chapter will discuss the implications of the findings from this study and will suggest further opportunities for research into the implementation of STEM education in Australia. This will provide a cohesive response to the overarching research question of this study: *What are the challenges facing STEM education in the Australian context*?

## 7.1 Introduction

In charting the introduction of STEM education in the Australian context attention was paid to when, where and who first used this term internationally and then in Australia. The context in which STEM education was introduced in Australia and what existed prior to its introduction were investigated. The context in which STEM education was introduced was one where governments were focussed on growing their nations' economies in a time of increasing globalisation. Governments, with their particular political agendas quickly became the prominent drivers of STEM education.

The literature review provided the context and timeline in which STEM education was introduced internationally and in Australia and also identified the three principal drivers of STEM education. These drivers were political, economic and societal or social cohesion. STEM education was expected to deliver a political agenda of growing the national economy to ensure continuing community prosperity and cohesion. The literature review also identified the key stakeholders who were advocating for the implementation of STEM education and the opportunities it would provide for young people and those who were raising concerns about issues associated with its development and implementation.

The curriculum development framework used to underpin this study drew on the work of nine international and Australian education researchers. There were five phases of curriculum development from the 1850s into the 2000s included in the framework. The framework was consistent with that proposed by DeBoer (2014) for the development of science curriculum. In chronological order from the 1850s, the phases were *Empiricism* (1850-), *Progressivism* (1901-), *Nature of Science* (1950-), *Neo-progressivism* (1970-) and *Standards-based reform* (1990-). These five phases were found to be present in Australian Curriculum learning areas and formed an appropriate lens to investigate the introduction, implementation and challenges for STEM education in the Australian context.

The analysis of selected document that were representative of the published authority was undertaken to identify any common themes amongst the documents. Further analysis was also undertaken to determine if and how these themes related to the curriculum development framework.

A Delphi study was undertaken to determine how a group of selected participants from across Australia understood the purposes of and the requirements for the implementation of STEM education in the Australian context. How each participant conceptualised STEM education and how this influenced their choice of a preferred vision for STEM education was also investigated.

Semi-structured interviews with the participants who had participated in the Delphi study and a small group of selected participants who had not participated in the Delphi study were conducted to further explore what support the implementation of STEM education required now and would require into the future.

A narrative inquiry approach was used to capture and present the voices opinions, ideas and experiences of the selected participants in this study. This enabled the inclusion of quotes from the participants as data to support the findings from this study and to also record comments from participants that were shared with other participants or were unique to one participant. This led to the identification of the challenges for STEM education in the Australian context.

### 7.2 Introduction of STEM education to Australia

The literature review identified several acronyms and terms in use in the 1990s that preceded the use of STEM and STEM education internationally. In the USA these included METS and SMET (Breiner et al., 2012). In the UK, SMET and STE were used (Wong et al., 2016). In responding to concerns about the quality of science education in the USA, the National Science Foundation (NSF, 2001) first introduced the acronym STEM. The NSF later extended the acronym to STEM education. This was done to strengthen its importance in preparing students for future careers and employment opportunities in STEM and STEM related fields It is also worth noting who first introduced STEM education in different countries. In the USA is was the NSF, a government agency whereas in the UK it was a government committee chaired by a prominent engineer. In Australia STEM and STEM education were introduced in 2013 by Dr. Chubb, Chief Scientist (2013a, 2013b). This later introduction in Australia meant that the discussions and debates about the order of the

disciplines or letters in STEM were avoided. However, recently in Australia, discussions have questioned the inclusion of mathematics asking if its role is that of supporting the other three disciplines, rather than as an integral component of STEM education. Participant X highlighted this issue in their semi-structured interview.

The conditions that led to the introduction of STEM education in Australia were very similar to those experienced internationally (Blackley and Howell, 2015). Blackley and Howell (2015) listed these as the impact of rapid development and applications of digital technologies and robotics on traditional manufacturing operations, increased globalisation and competitiveness, a shift in the type of skills needed to grow economies and maintain social cohesion and a sense that the education of young people was not meeting expectations or equipping them for twenty-first century careers and employment. Rather than following the approach of USA or UK, in this instance Australia may be better served (Blackley and Howell, 2015) by considering the global STEM education offerings from the geo-social approaches and selecting or modifying international resources that best fit the Australian context as presented in Chubb's social compact (2013a). Such resources will also need to align with STEM education policies from the federal, state and territory governments to gain acceptance and to attract funding to support and track their use in schools. These resources would also need to consider and address the diversity that exists in the student population in two areas across Australia. First is the geographical location of the schools - metropolitan (large cities predominately located in the eastern states of New South Wales, Victoria and Queensland) or regional, rural or remote (mostly isolated areas across northern and central Australia) leading to differences in local context and in the level of access to organisations and services available to implement STEM. Second is the diversity in the multicultural and socioeconomic background of the student population of Australian schools. As with geographical location this diversity will also influence the choice of content included and the type of additional support required, for example, raising the levels of literacy and the use of culturally sensitive content and pedagogy.

Similarly, many of the issues that underpinned the implementation of STEM education internationally (Freeman et al., 2015) were applicable to Australia. Examples of these issues were the type of knowledge and skills included in STEM education and the possible approaches to the delivery of STEM education. Another issue was the provision of access and equity of access to STEM education programs in early childhood or school or tertiary education or in job training settings. The supply of a sufficient number of highly qualified

teachers and educators in the STEM disciplines and to staff these programs will become an issue as more young Australians seek careers and employment in STEM and STEM related areas (Marginson et al., 2013). To provide a STEM skilled workforce to meet the demands and challenges of growing Australia's economy will require the provision of ongoing funding to support STEM education programs(EA, 2017). Chubb (2013a) argued that the use of a *Social Compact for a Better Australia* provided opportunities for Australia to embrace STEM education that reflected the diversity of the population of Australia.

### 7.3 Curriculum development framework

The curriculum development framework that underpinned this study was supported by the investigation of how the work of the nine selected education researchers linked to STEM education.

Huxley, working from the Empiricism phase of curriculum development, emphasised the development of specific skills within particular knowledge contexts. This equated with development of a workforce with STEM skills as providing employment and career opportunities.

Dewey, working from the Progressivism phase of curriculum development, emphasised the provision of learning experiences that build from the individual's interests and needs that would enable them to become an active member of their community. This suggested that in developing STEM education programs the emphasis should be on the provision and delivery of activities that build the knowledge and skills the individual requires.

Tyler, working from late Progressivism and the Nature of Science phases of curriculum development, proposed the use of outcomes to assess the students' achievement from a sequence of learning experiences. If the achievement standards of the Australian Curriculum were equated to Tyler's use of outcomes, then STEM education programs would require the provision of appropriate sequences of learning experiences that matched these standards. Ongoing review and evaluation of the standards and the learning sequences would address the accountability expected in the Standards-based reform phase of curriculum development.

Schwab, working from the late Nature of Science and into the beginnings of the Neo-progressivism phase of curriculum development, focussed on supporting teachers to design, implement and evaluate their own curriculum to best suit their students. This would facilitate the use of multiple approaches to the development of a set of STEM skills and associated knowledge. Such an approach would require ongoing professional development and learning

that addressed both pedagogical practices and discipline knowledge to ensure all students achieve the best outcomes.

Young, working across the Neo-progressivism and into Standards-based reform phases of curriculum development, investigated what and whose knowledge is included in a curriculum and if this knowledge can be developed from different contexts. From the perspective of STEM education, examples of suitable contexts and associated tasks that will enable students to acquire what he described as *powerful knowledge* will be required. However, care would be needed to ensure that the learning experiences provided to build this knowledge are accessible to and engage all students.

Bybee, like Young, was working across the Neo-progressivism and Standards-based reform phases of curriculum development. He focused on the development of the approaches to STEM education that will accommodate its existing multiple purposes and requirements for implementation. Bybee argued that educating students to become informed citizens who are capable of understanding and addressing global challenges should be given prominence regardless of which particular approach to implementation was used. He continued to refine the *5E instructional model* he developed in the 1980s to make it applicable to and supportive of implementing STEM education programs.

Concerns were raised (Freeman, 2014, Chubb, 2013a and National Science and Technology Council USA, 2013) related to the engagement of students, increasing student achievement and providing greater access for students to study science and mathematics at and beyond secondary school. Improving the engagement of students has been and continues to be a concern across all phases of the curriculum development framework and for curriculum researchers such as Boomer, Dewey, Fensham and Young. Past attempts to address this issue have led to improvements and changes in the design of curriculum and pedagogical and assessment practice, but as Tytler (2007) showed many students' attitudes towards science remain negative. The implementation of STEM education offers opportunities to further innovate current practices to provide high-quality education that is accessible to and engages all students.

The focus on teacher quality, teacher training and professional learning and meeting community expectations as of what young people should learn or know or be able to do has remained a constant focus across all the phases of curriculum development and the work of the education researchers. Research from the six international education researchers with

expertise in curriculum contributed to the curriculum development framework used in this study (chapter 2). This also raised ideas and issues related to student engagement and access and equity of access, curriculum, pedagogy, assessment, professional development, teacher quality and training and accountability.

The research from the three Australian education researchers also contributed to the curriculum development framework used in this study (chapter 2). Fensham (1986 and 2016), who began working from late in the Nature of Science and into the Standards-based reform phases of the curriculum framework, argued that, changing the design, structure and content of curriculum necessitates new approaches to pedagogical and assessment practices if the intended curriculum is to be enacted by teachers. This would include addressing issues associated with access and equity of access of students to the intended curriculum (Marginson et al., 2013).

Boomer worked during the Neo-progressivism and into the Standards-based reform phases of curriculum. He focussed on the role of education in addressing disparities across Australia in access and equity of access to a high-quality education. He strongly advocated for education policies and curriculum that promoted social justice. Boomer (1992) acknowledged the influence of the political agenda and economic conditions on the funding available for education.

Tytler, working from the Neo-progressivism phase and into the Standards-based reform phases of curriculum development, was interested in the innovation in pedagogical and assessment practices required to better engage students in their learning. He (2007) sought to re-imagine science curriculum that would include scientific literacy to develop informed citizens, well prepared to manage their futures. Tytler suggested that this would include programs that made connections between learning areas of the Australian Curriculum and developed skills in problem solving, teamwork and critical and creative thinking. He argued such an approach would increase student engagement and develop more positive attitudes towards science and mathematics.

In the context of increasing globalisation, governments were seeking ways to grow their nation's economy and looked to education to better prepare young people for employment in STEM and STEM related fields. New curricula were developed and focussed on addressing student engagement, achievement and outcomes. One such curriculum developed in the USA was the *Next Generation Science Standards* (NGSS, 2013). Although both the NGSS (2013)

and the Australian Curriculum (AC) sought to include engineering in the school curriculum, the approaches taken to do this were quite different. The NGSS (2013) included engineering practices as part of the Science learning area K-12 whereas the Australian Curriculum (AC) F-10 included the design process associated with engineering in the Technologies learning area with the science and mathematics learning areas contributing relevant knowledge and skills as appropriate. However, both the NGSS and AC focussed on making connections between the different branches of Science. The general capabilities from the AC related to thinking, problem solving and teamwork skills were also presented as contributing to the inclusion of engineering in the curriculum. Both approaches sit comfortably within the Standards-based reform phase of curriculum development and have each retained aspects of the previous phases, for example, an emphasis on access for all and nurturing the development of generalist and specialist knowledge.

The use of the curriculum development framework to underpin this study has suggested that further discussions would be beneficial as to how the Australian Curriculum would deliver outcomes expected of STEM education in Australia including increased enrolments in senior secondary high-level mathematics and physics or in tertiary science and engineering courses.

### 7.4 Document analysis

The author or commissioning agency of each of the selected documents had a particular agenda (Bowen, 2009 and Rapley, 2007). This was evident in the intended purpose and audience of the documents. For example, Engineers Australia (EA) has a responsibility as a professional association to look after the interests of its members, including maintaining the level of qualifications and certification required to be a registered engineer in Australia. As such, EA is likely to be less supportive of government policies that sought to relax these regulations in order to register more engineers to ensure the government's agenda of economic growth is sustained. This example of a difference in opinions between stakeholders in their expectations of STEM education was evident across some of the documents analysed. It also suggested that establishing partnerships to implement STEM education requires mutual respect and a shared understanding of what outcomes a particular program is expected to deliver.

When analysing the documents, evidence of the context, for example the time period, political or economic or social context in which these were published and their relationship to

the expected outcomes and the intended audience, was provided (Codd, 1986, Altheide, 2000, Coffey, 2013). It was also important that differences in opinions between the stakeholders in STEM education that could likely lead to possible tensions were captured and reflected in the analysis of the documents.

The analysis of the selected documents identified five themes. First was *engagement of students* which emphasised the relevance and currency of the content of the resources used by students and their community. The documents provided examples as to how to better engage students in learning in STEM education, including utilising the local community as the context for learning.

Second was *access and equity of access* to opportunities in STEM education for all students regardless of gender or socioeconomic status or location or culture or ethnicity. Access and equity of access did not necessarily mean equal access. Given the differences in geographical locations of schools and the student population in Australia, the nature of the local community or environment is diverse. Consequently, the opportunities for STEM education for students at the local level is very different across Australia. What is important is that the students regardless of location have access to the resources they need in person or via digital communications to ensure equity of access.

Third was *curriculum content* that focused on the inclusion of STEM knowledge and skills at two levels. One was the provision of general STEM education for all students in the compulsory years of schooling. The other was a more specialised STEM education for those students wishing to pursue studies in STEM beyond the compulsory years of schooling. This could be expected to lead to greater employment in STEM and STEM related jobs and more informed citizens.

Fourth was *pedagogy* that focused on the variety of approaches available for the delivery of STEM education. Approaches included integration of some or all of the STEM disciplines, interdisciplinary or multidisciplinary or a combination as appropriate to the topic or task. The approach taken was seen as being dependent on the age or year level of the students with integration usually preferred in primary education programs and an interdisciplinary approach more usual in the compulsory years of secondary education. In the Australian Curriculum for the senior secondary years there are separate science (e.g. biology, chemistry and physics) and mathematics (e.g. general mathematics, specialist mathematics) subjects offered.

Fifth was *assessment* which included both summative and formative assessment practices that were implemented as most appropriate to the age and level of the students or most relevant to the tasks the students were expected to complete. Assessment was also presented as an accountability measure for student progress and achievement against set standards. The collection and analysis of assessment data could then be presented as the evidence that new initiatives or programs being implemented to deliver STEM education were successful or could point to areas were improvements or further reforms where required.

The five themes that emerged from the document analysis were also evident in more than one phase of the curriculum development framework. These findings supported the suggestion that elements of the preceding phase of curriculum development were still evident or remained in successive phases, albeit with a change of emphasis to reflect the political, economic and social environment. They also supported the use of the curriculum development framework to underpin an investigation of STEM education in Australia. These five themes were also consistent with the key findings for the implementation of STEM education in Australia (Marginson et al., 2013).

### 7.5 The Delphi study

There were three questionnaires completed by eleven participants in the Delphi study. Three possible visions for STEM education in the Australian context were presented in the third questionnaire. These visions were developed from the analysis of data from the first and second questionnaires. When these visions were presented to the participants, their choice of preferred vision and reasons for their choices were different. This was to be expected as the choice of vision reflected of how each participant conceptualised STEM education. This in turn was shaped by their experiences and expectations. This diversity in opinions is to be encouraged as it fosters professional conversations about how to successfully implement STEM education that achieves the best outcomes for all young Australians.

The Delphi study also showed that it was possible to construct multiple visions for STEM education in the Australian context which focussed on economic or social prosperity through education, employment and engagement of students leading to citizens capable of making informed decisions.

## 7.6 Linking the visions to the curriculum development framework and document analysis

### 7.6.1 Vision 1

STEM education contributes to a broad suite of learning experiences that enable all young people to participate in and contribute to building sustainable communities.

In this vision:

- *broad suite of learning experiences:* presented STEM education as one component of the education provided to young people with an emphasis on breadth and is representative of the theme of curriculum content from the document analysis.
- *enable all:* focussed on access and equity of access for all that supports young people to be engaged and active in their communities and is representative of two themes identified in the document analysis.
- *participate in and contribute to*: placed the emphasis on the individual and as a member of a group and their role in building social cohesion. Although not specifically evident as a separate theme from the document analysis, fostering participation and contribution could be equated to increased engagement of young people in their learning by using their local community as a context.
- *building sustainable communities:* focussed on social cohesion within communities, the management of the environment both locally and globally and the use of resources. This could be an example of accountability for economic prosperity now and into the future. Although this was not identified in the document analysis, the concept of sustainability and its application could become a focus for extending the breadth of STEM education as opposed to keeping the emphasis on just economic growth. It could also provide a context for the delivery of the curriculum, reflecting the themes of curriculum content and pedagogy in the document analysis.

Vision 1 was linked to four phases of the curriculum development framework as follows:

- *broad suite of learning experiences:* reflected the Progressivism and Neo-progressivism phases of the curriculum development framework where the focus was on the learner and their engagement with an education program at the local level that was relevant to them now and in their future.

- *enable all:* reflected the Neo-progressivism phase of the curriculum development framework in the provision of access and equity of access for all young people with some elements from Empiricism and Nature of Science phases of the curriculum development framework which focussed on providing generalists, technicians and specialists.
- *participate in and contribute to:* reflected the Neo-progressivism phase of the curriculum development framework with some elements from the Empiricism phase such as learning from working with specialists or experts to build to sustainable communities.
- *building sustainable communiti*es: reflected the Neo-progressivism phase of the curriculum development framework with concerns for the environment and its future and how the earth's resources are utilised, reused or recycled.

Vision 1 did not specify knowledge or skills or a particular pedagogy to deliver STEM education. Rather it suggested that the different areas of the curriculum be brought together to provide the learning experiences that support young people to have input into shaping their futures. The inclusion of *sustainability* sought to provide a context that was of relevance and interest to the learners and reflected a renewed focus on communities and their environment. This vision has a strong focus on community, which could be seen as an example of the social cohesion and prosperity context for STEM education. This vision was predominantly representative of the Neo-progressivism phase of curriculum development with some elements of the Empiricism, Progressivism and Nature of Science phases included. However, it did not explicitly address the Standards-based reform phase of curriculum development. To do so would require examples of the knowledge and skills expected to be addressed and assessed in the learning experiences. This vision articulated government and societal agendas with respect to what STEM education is expected to deliver.

### 7.6.2 Vision 2

STEM education provides the skills that enable all young people to contribute to growing the nation's economy and global competitiveness.

In this vision:

- *skills:* the specific focus was on those skills with a direct connection and application to what the economy requires to grow. The inclusion of these skills pointed to the

structure of a curriculum that included skills development and application. Curriculum content was a theme identified from the document analysis.

- *enable all:* emphasised the inclusion through access and equity of access and engagement that supports young people to contribute to the nation's future. This is representative of two of the themes identified in the document analysis.
- *contribute to growing*: addressed economic and social prosperity where all young Australians have the capacity to participate. Although not a specific theme identified in the document analysis, it could be part of the engagement of students in and with learning and with the community and was representative of a theme from the document analysis.
- *nation's economy and global competitiveness*: provided a context for the development of skills that was linked to current and future prosperity. This implied that engagement of the young person as a learner was important and was representative of a theme from the document analysis.

Vision 2 was linked to the five phases of the curriculum development framework as follows:

- *skills:* reflected the Empiricism, Nature of Science and Standards-based reform phases of the curriculum development framework
- *enable all:* reflected the Neo-progressivism phase of the curriculum development framework with some elements from the Empiricism phase with its emphasis on skills development linked to economic prosperity
- *contribute to growing:* reflected the Progressivism phase of the curriculum development framework
- *nation's economy and global competitiveness:* reflected the Standards-based reform phase of the curriculum development framework.

Vision 2 grounded STEM education as an economic and political initiative with an emphasis on the acquisition of skills directly related to growing economic prosperity and, by inference, social cohesion. It did not specify how the skills would be acquired or if particular knowledge was also required. This could be achieved by taking either a content or a context-based approach to developing and implementing STEM education programs. The vision was situated in the now but the use of growing suggested looking to the future. Assessment was implied in that the skills acquired were expected to drive economic growth as an outcome.

This vision clearly articulated government, business and industry agendas with respect to what they expect STEM education to deliver. This vision has a predominant focus on the development of a skills set with a specific expected outcome and as such introduced an accountability element to the implementation of the vision.

### 7.6.3 Vision 3

STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which live now and into the future.

In this vision:

- *equips all:* emphasised inclusion through access and equity of access, engagement of the learner and pedagogical practices inclusive of all learners. This reflected three of the themes identified in the document analysis.
- *knowledge and skills:* provided the content to be included in curriculum documents. Curriculum content was a theme identified in the document analysis.
- *understand:* emphasised the application of knowledge and skills and pointed to assessment. Assessment was a theme identified in the document analysis.
- *complex and challenging nature of the world:* emphasised relevance to the learner, engagement of the learner and relevance of the content presented in the curriculum. Curriculum content and engagement of students were themes identified in the document analysis.
- *now and into the future:* focussed on short and longer-term outcomes and accountability. Although not specifically identified as a theme in the document analysis, accountability could be measured through the assessment of achievement. Like Vision 1, the focus on now and the future could provide a context for the curriculum or for its delivery including the themes of curriculum content and pedagogy.

Vision 3 was linked to the five phases of the curriculum development framework as follows:

- *all* and *knowledge and skills:* reflected the Progressivism, Neo-progressivism, Empiricism and Nature of Science phases of the curriculum development framework.

- *complex and challenging world:* as contexts reflected the Progressivism and Neo-progressivism phases of the curriculum development framework.
- *understand and now and the future:* reflected the Standards-based reform phase of the curriculum development framework.

Vision 3, like the other two visions, did not specify a particular mode of delivery for STEM education. Rather it was underpinned by the provision of learning that remains relevant to and engages young people. The purpose that flows from the vision is to equip young Australians for now and the future in what is acknowledged as a complex and challenging world. In so doing, it also allows for a speculative approach to the future. The vision extends from the acquisition of particular knowledge and skills to understanding. It reflected the government agenda where STEM education engages all young people and equips them for the future. This vision focussed on building understanding rather than contributing to the community or growing the economy as included in Vision 2 and Vision 1. As such Vision 3 is applicable to education more broadly than just STEM education and suggests that to contribute to economic and community prosperity requires particular knowledge and skills. The five phases of the curriculum development framework were evident in this vision.

The analysis of the three visions developed in this study illustrated that elements from the different phases of curriculum development are able to coexist within a particular phase and can be subsumed into succeeding phases.

### 7.6.4 Overview of the visions

The three visions developed in this study are goal oriented rather than specifying what content needs to be taught, how it is taught and how it would be assessed. These visions were also inclusive of all young people and were future focused. If building sustainable communities from Vision 1 and understanding the complex and challenging nature of the world from Vision 3 were seen to include economic prosperity and employment opportunities, then the economic driver for STEM education would be implicit in these two visions rather than explicit as in Vision 2. This suggests that the three visions could be merged into one overarching vision. If such a vision were developed, it would need to accommodate the different conceptualisations of STEM education that this study has demonstrated, and that are likely to exist amongst educators and those interested in STEM

education. What this vision would look like and the benefits it would deliver require further research.

The choice of preferred vision, the reasons for this choice and the requirements for its implementation varied amongst the Delphi study participants. For example, the development of STEM education knowledge and skills within and across the disciplines was used to support the implementation of Visions 1 and 3, and providing employment opportunities for young people was used to support the choice of preferred Visions 2 and 3. Pedagogical practices and ongoing professional development were used as reasons to support the choice and implementation of all three visions. Similarly, the Non-Delphi study participants used different reasons for their choice of preferred vision. For example, contributing to the community was used to support the implementation of Visions 2 and 3, and managing the future (complex, challenging, changing) was used to support Visions 1 and 3. Economic growth and prosperity was used to support the implementation of all three visions.

The diversity in reasons participants used to support their choice of vision between all participants was to be expected given that each had a different conceptualisation of STEM education. In the Delphi study, the participants were asked to select their reasons for their choice of preferred visons from the list of pivotal statements provided. These statements were developed using the analysis of data from the two previous Questionnaire. The Non-Delphi study participants were asked to explain their choice of preferred vision without any prompts. The difference in approaches also contributed to the diversity of reasons. In future research it would be interesting to ask the Non-Delphi study participants to explain their choice of preferred vision using the list of pivotal statements from the Delphi study and to compare this data with that from the Delphi study participants. This was not done in this study, as only the three visions developed were presented to the Non-Delphi study participants to determine the trustworthiness (Hasson and Keeney, 2011) of the data collected from the Delphi study. Future research could also investigate which and why any of the three visions from this study were preferred by a different group of participants, for example, teachers of STEM education or people developing resources for STEM education.

The visions for STEM education in the Australian context developed from the Delphi study shared characteristics with the international visions for STEM education from UK STEM Learning Centre (2006), the Republic of Ireland (2018), Department of Education (USA, 2016) and the European Union (2016). The focus of these international visions was the relationship between economic growth and social cohesion, access to high-quality STEM

education for all young people and the role of STEM education in developing informed citizens and decision makers who contribute to the nation's future. The visions developed in this study were similar to the international visions discussed in chapter 2. From Vision 1, building sustainable communities could be equated to providing social cohesion and contributing to the nation's future. From Vision 2, skills and contributing to growing the economy could be equated to the access to high-quality STEM education and securing the nation's future. From Vision 3, the knowledge and skills and the current and future challenging nature of the world could be equated to the access to high-quality STEM education and its role in developing informed citizens and decisions makers and the nation's future. The relationship between economic growth and social cohesion was not explicit but rather implied in the visions. If building sustainable communities is seen as producing an economic advantage, for example in reducing waste and greater use of recycled water, then Vision 1 provided evidence of the relationship between economic growth and social cohesion. If having the skills to grow the economy is seen as more people being employed and contributing to the nation's future, then Vision 2 also provided evidence of the relationship between economic growth and social cohesion. If being able to understand the world now and in the future is seen as including the role of the economy and how to contribute to communities, then Vision 3 provided some evidence of the relationship between economic growth and social cohesion.

This suggests that implementing visions for STEM education in the Australian context could be achieved through innovative curriculum and pedagogical practices that build foundational knowledge, skills and understandings in the disciplines of STEM. This would contribute to the development of informed citizens and provide the next generation of specialists and technicians who are able to grow and secure Australia's economic and social prosperity. The provision of ongoing professional development programs for educators was also seen as critical to implement visions for STEM education in international settings and in Australia. The valuable role of partnerships between the groups interested in STEM education to support its implementation is also shown by *STEMinc.* (Singapore). There are examples of partnerships from *STEMinc*. between students, families, schools, local higher education programs and business and industry that could be a model for Australia.

As suggested by Tytler (2007), Breiner et al. (2012), Johnson (2012, 2013), Wong et al. (2016) and Blackley and Howell (2015) what matters was that the visions constructed for

STEM education in the Australian context are coherent and their intent and purpose was shared and understood by those responsible for its implementation.

A preferred vision for STEM education in the Australian context did emerge from the Delphi study. This was Vision 3: STEM education *equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they live now and into the future.* This vision is much broader than just for STEM education. It speaks to a vision for the whole education of all young Australians. The reasons given for the choice of this vision varied as was the case for the other two visions. Interestingly the same two reasons related to pedagogy and ongoing professional development for teachers were cited by the participants to support the implementation of all three visions.

### 7.7 Semi-structured interviews

The analysis of the transcripts from the sixteen participants who were interviewed identified examples of the types of events discussed by Webster and Mertova (2007) and Daiute (2014). These included examples of events identified as *critical* or *significant*, *like* or *other* events. An example of a *critical* event (Webster and Mertova, 2007:p.79) occurred when one participant noted that those who should be responding to a new initiative sometimes do not engage with it or assume a negative stance to it. This action effectively removes these people from being included in any further discussions and decisions related to the new initiative, diminishing their ability to influence and impact the new initiative. A similar *critical* event occurred when another participant focussed on the importance given to increasing the numbers of secondary school students enrolled in STEM education programs at a time when the availability of suitably qualified teachers in the disciplines of STEM was steadily declining. This event then raised the quality and type of pre-service teacher education offered at a tertiary level and the recruitment of suitably qualified teachers as an issue that would requires consideration.

In the semi-structured interviews, one participant's concern about the role of assessment in STEM education was explored with other participants. This led several participants to broaden their advice for STEM education to include the review of current assessment practices or the use of more innovative assessment practices. This is an example of an *other* event, where the response from one participant was taken up by other participants and so raised the issue of assessment to a *like* event (Webster and Mertova: p.79).

The choice of visions and the reasons given for the choice by the Non-Delphi participants reflected those of the Delphi study participants and demonstrated that it was possible to build trust in the analysis of data from a Delphi study as argued by Hasson and Keeney (2011).

The semi-structured interviews provided insights into how the participants viewed their participation and contribution to this study. Most participants described themselves as educators with experiences in teacher education, research or leadership. Some participants focussed specifically on being a STEM educator or from a STEM background. The similarities in and the diversity of experiences and opinions related to STEM education in the Australian context generated a breadth and depth of responses to the questions asked in this study.

The semi-structured interviews showed that much could be learnt from past experiences in education reform to enhance the implementation of STEM education in the Australian context. These included:

- the importance of the timely provision of high-quality resources prior to and during implementation of the reforms to assist educators build their conceptualisation of the reform and to develop the knowledge and skills required to implement the reform and deliver the desired outcomes. This would require a commitment to ongoing professional development or learning opportunities to support educators to enhance the quality of teaching and learning for all young Australians.
- the alignment of policies and programs related to the reform to ensure that the curriculum and assessment practices were consistent with the rationale of the reform and encouraged innovative pedagogical practices. For example, the construction of tasks that allowed students to demonstrate and challenge their understanding or their application of critical and creative thinking and problem solving skills to current, future and “what if issues” and problems.
- the development and publication of evaluation strategies to determine the progress and effectiveness prior to the beginning of the reform and to support revisions where and when necessary during its implementation of the reform.
- the provision of advice and examples as to how to establish and sustain partnerships between stakeholders with an interest in the reform at the local level. This would include the identification of suitable stakeholders.

The semi-structured interviews also identified considerations for the future for STEM education in the Australian context, including:

- to re-engage the *voices of education* in the debates and discussions about STEM education, its applicability and implementation as part of education for all young Australians.
- to investigate whether, like Europe, Australia includes social responsibility as part of the STEM disciplines as appropriate.
- to look beyond the current disciplinary based curriculum to the possible development of a curriculum with inter-disciplinary and new learning areas.
- to investigate the provision of high-quality, contemporary and credible resources and ongoing professional learning and conversations that build teacher confidence and competence.
- to consider what the inclusion of the Arts and Humanities in STEM education would offer STEM education.

The themes of curriculum content and its relevance and interest to students; pedagogy and how to best deliver STEM education programs; teacher quality and professional development; and accountability as expectations of governments, business and industry and community; were evident in the responses to many of the interview questions from both the Delphi study and Non-Delphi study participants.

### 7.8 Conceptualisation of STEM education

In this study, an innovative approach was used to investigate how the participants conceptualised STEM education. Each participant's conceptualisation of STEM education was constructed using the analysis of the data collected from the Delphi study and the semi-structured interviews. These conceptualisations were then used to explain the diversity of opinions and ideas expressed by the participants and assisted to identify the challenges facing STEM education in the Australian context.

The choice of preferred visions and the reasons for these choices were dependent on how the participants conceptualised STEM education. This was to be expected as the conceptualisation of STEM education is reflective of the individual's experiences and opinions. The conceptualisations presented were multifaceted and acknowledged the purposes of STEM and the opportunities it offers. It was also reflective of the participants' experiences with past attempts, both successful and unsuccessful, in education reforms.

There were similarities in the conceptualisations of STEM education between all the participants in this study. Participants B, E and X focussed on economic prosperity as the driver of STEM education. Participants F, K and P included employment and workplace skills which could be seen as examples of the economic and political drivers for STEM education. Participants A, D, H, T and Y highlighted the importance and inclusion of the engagement of students with real-world problems and issues as a necessary component of STEM education programs. Participants C, G, L, M, R and S focussed on pedagogical practices and the relationships between the disciplines which could be seen as an integral component of the professional learning required to implement STEM education.

These conceptualisations related to the five themes of engagement of students, access and equity of access, curriculum, pedagogy and assessment that emerged from the document analysis undertaken in this study. Reference was also made to the economic, political and social drivers of STEM education. This was consistent with the literature review and pointed towards the challenges for STEM education both in the Australian context and internationally.

In this study, the participants' conceptualisations of STEM education are similar to the clear and shared understanding Wong et al. (2016) argued was necessary to progress STEM education. As Wong et al. (2016) suggested, there was diversity in the conceptualisation of STEM education amongst the participants in this study. Four broad shared themes were present in the participants' conceptualisations of STEM Education. These were economic prosperity, engagement of students, pedagogical practices and relationships between the STEM disciplines. This suggests that collaboration between participants to deliver STEM education and to focus on the provision of a high-quality of education for all young Australians is possible. Given the differences in conceptualisations of STEM education among the participants in this study, debates and discussions about what a high-quality education would look like and how to best implement it would likely be intense and require some compromises to ensure the best outcomes for all young Australians.

The three contexts in which Breiner et al. (2012) suggested the conceptualisations of STEM education would be expressed by the participants were not explicit in this study. Some aspects of each context were found in this study. For example, the inclusion of references to the role of governments in employment and workplace skills in a participant's conceptualisation of STEM education could be seen as an example of the political context included by Breiner et al. (2012). If, in their conceptualisation of STEM education, a

participant referred to the use of real-world issues to deliver STEM education, this could be seen as an example of a societal context, as described by Breiner et al. (2012).

When reflecting on their inclusion in this study, all the participants identified key points or events or highlighted past achievements. They then looked to the future of education for young Australians, with a focus on the quality of this education. In describing which of their experiences impacted on their conceptualisation of STEM education and what was important or mattered to them:

- eight participants highlighted experiences in education research;
- seven participants identified experiences in teacher education;
- five participants pointed to their leadership of teams or projects or organisations;
- four participants specifically included being a teacher as being part of their current or past experience;
- three participants, all Non-Delphi, included being a STEM educator or from a STEM background.

The list of experiences that mattered to participants provided an interesting and unexpected response. The direct reference to STEM education and being from a STEM background was unique to several of the Non-Delphi study participants. It may have been that in describing themselves as an educator, the other participants assumed that this included STEM education or that being an educator meant they were interested in many different aspects of education or in the whole education program offered to all Australian students.

### 7.9 Implementation of STEM education in the Australian context

This study did not focus specifically on the ways in which STEM education was or could be implemented. Rather, the participants suggested a variety of approaches that included an integration of knowledge and skills from the STEM disciplines (English, 2017, Johnson, 2012, 2013 and NAE & NCR, 2014), an inquiry approach to solving real problems drawing on content from the relevant STEM disciplines (Fensham, 2016, Zeidler, 2016), building foundational knowledge, skills and understanding in science and mathematics, and the inclusion of specific skills, for example, critical and creativity thinking or design and innovation to develop a response to current issues of concern to young people.

In Australia, discussions about how to implement of STEM education have focussed on which approaches or pedagogical practices would be most appropriate. This was similar to

what had occurred internationally. For example, in a report published by the NAE & NCR (2014) about the integration of STEM education in the USA, it was suggested that multiple approaches to the successful integration of the STEM disciplines were possible. However, to ensure successful implementation, the report recommended that a coherent and explicit strategy for STEM education was required. Such a strategy would include support for teachers, schools and systems in the form of funded professional development in pedagogical practices and the disciplines of STEM, innovative resources and ongoing review and evaluation processes. The findings from the Delphi study and the semi-structured interviews undertaken in this study identified that this type of support would also be crucial to the successful implementation of STEM education in the Australian context.

In the Australian context, using the Australian Curriculum to enact a vision for STEM education would see the focus on the use of local contexts that resonated with the interests and needs of students and their community. As we see in the different visions for STEM education proposed in this study, this suggests there would likely be multiple approaches to ensuring its successful implementation.

The visions constructed in this study provided examples of possible directions for the development of STEM education programs. For example, the implementation of a high-quality STEM education for all young Australians requires teachers to have the knowledge and skills to help students become informed citizens capable of managing their futures in a context of economic growth and social prosperity.

### 7.10 Reflecting on the researcher's stance

In chapter one of this research I explained why I undertook this study. As I was using a narrative inquiry approach in this study, I acknowledged that given my experiences in education, I would be both a researcher and a participant in this study as discussed in the declaration of my stance in chapter three.

The participants in this study were provided with opportunities to raise questions or issues related to the Delphi study and the semi-structured interviews. Four participants took the opportunity to raise issues that challenged me to reflect on and further clarify my declared stance as discussed below.

During one interview, a participant asked if all the participants in the research were from academia. My response to this question was deliberately general, for example, "participants included a research scientist, a former senior education bureaucrat and a person

with business experience." In forming my response, I sought to show the breadth and richness of experiences that the participants brought to the study whilst ensuring I complied with preserving the anonymity of all participants as required by the conditions of ethics approval.

It could be argued on reflection that I had assumed that the careful selection of the participants using the selection criteria I developed and applied as discussed in 3.3.5. would provide a diversity of opinions that could both inform and challenge how STEM education is understood and implemented in the Australian context. It could be argued that given my experiences, I may have unconsciously already assembled a list of possible participants and that this may have impacted on the selection criteria developed. Similarly, it might be claimed that my conceptualisation of STEM education as a positive and a necessary addition to the education of all young Australians would impact on who was selected to participate in the research. In response, it could be argued that this has been addressed by the published declaration of my stance, the published the selection criteria, and the presentation of the findings from this study as being from a particular group of participants, at a particular time and in response to particular questions.

During another interview, a participant who self-identified as a non-STEM person queried their inclusion in the research. I explained that I was interested in investigating how a participant with a non-STEM background and with published research in all areas of curriculum would conceptualise STEM education and envision its implementation in the Australian context.

Another participant, when commenting on the Delphi study suggested that a rather provocative question, for example *Is STEM a fad?* could have been included in Questionnaire one. I decided not to explicitly provoke the participants by asking such questions. Rather I chose to offer the participants the opportunities to provide any additional comments on each questionnaire in the Delphi study and a question asking for other comments in the semi-structured interviews to capture further information or controversial statements.

As the researcher I have continued to reflect on the data analysis and findings and have come to understand that I have taken it as given that STEM education has a place in the education of all young Australians. It could be argued that I have likely been influenced by government documents and the published literature supporting STEM education and in turn I am likely to have influenced the choice of documents analysed, the selection of participants

and the construction of the questions used in the Delphi study and semi-structured interviews that were part of this study. This did not lessen the value of the findings from this study, rather it strengthened the argument that how STEM education is conceptualised is personal and reflective of an individual's experiences, beliefs and values and that this diversity leads to a professional discourse that challenges educators to find common or shared understandings.

In commenting on the Delphi study, one participant suggested that as the researcher I was *favourably disposed* towards STEM education and this was evident in the questions asked on the second questionnaire that related to the suitability of using a ranking system. The participant explained that they "*felt somewhat boxed in by an invisible set of assumptions and that an objectivist, value-neutral standpoint was being assumed by the researcher*." The participant further argued that the use of a ranking system suggested that the researcher expected a particular hierarchy of responses.

As declared in my stance (3.1.4), I did not consider myself as having a neutral standpoint or as being separate to and from this study. I am, by my very interest in STEM education and my experiences in education, an integral part of this study and as such I bring particular beliefs and values to the research. This includes a deep interest in curriculum and in the future education offered to young Australians and a curiosity as to the prominence currently given to STEM education in Australia. An example of my stance that is not neutral is in the use of equity of access rather than equal access. For me, equity of access means that all young Australians have access to education that is relevant and meaningful to them in their local context and for their future. It does not mean that all young Australians receive exactly the same education at the same time. Consequently, I accept that STEM education should be tailored to serve the needs of different students. For example, if a rural community is working on a local project that requires access to a space scientist, then equity of access would ensure that they were connected with a space scientist. Geographical location or the nature of the student population should not exclude any school from completing its local education program. What this does challenge is the use of national testing programs at a specific time of the year and for a particular level as a way to achieve accountability of outcomes in the Standards-based reform phase of curriculum development. I do accept the requirement to assess student progress and achievement as part of the accountability framework for education programs in Australia. However, I question if national or international testing programs are the best way to do this. My stance demonstrated my

commitment to supporting the education of the whole person as an individual with particular experiences, interests and expectations and as a valued community member.

The questions asked in the Delphi study and the semi-structured interviews were designed to elicit opinions and ideas, with similarities and differences identified and not to set a direction for the responses or to support a particular position for STEM education. My aim was to present the participants' perspectives, not to make generalisations that would apply to all people with interests in and working in STEM education and related areas in Australia.

When reflecting on how the selected participants described their participation in this study, I noted that only three participants included in their description of their experiences being a STEM educator or from a STEM background. This low number surprised me and led me to reflect on something I had not previously considered. This was whether I would regard myself as a STEM educator or having a STEM background. It also made me consider what being a STEM educator or having a STEM background meant and if a greater involvement in the implementation of STEM education and associated research would lead to more participants identifying as STEM educators or having a STEM background.

If I had been asked to describe my role in education, I would have answered as a teacher first, then would have added teaching senior Chemistry and Mathematics and general science subjects. If being a STEM educator was to mean teaching and researching STEM education, and having a STEM background was to mean a tertiary education in two or more of the STEM disciplines, then I would be described as a STEM educator with a STEM background! This suggested that future research could investigate what it means to be a STEM educator and how this would impact on the development, implementation and evaluation of STEM education as part of a Delphi study or as a question explored in semi-structured interviews.

By acknowledging and declaring my stance in all aspects of this study as discussed above and as reflected in the findings presented in chapters four, five and six I have sought to build the credibility of this study.

I also believe that the voice of education as expressed by academics, teachers and principals has been absent from the high-level debates and discussions related to STEM education in the Australian context. In undertaking this study, I have sought to provide the participants with the opportunity to voice their opinions, ideas and concerns related to STEM education and to have a place in the crucial debates and discussions about the education of young Australians. To present and respect their voices I have included direct quotes as data in

this research. The selection and interpretation of these quotes has been done with the aim of representing the integrity of their voices and respect for their past experiences and commitment and contributions to education, ensuring the best education possible is available to all young Australians.

As I stand back from this study, I am able to reflect on the questions and issues related to STEM education that for me remain unresolved. Does the order of the letters in the acronym STEM matter? As it is written, S and M could be seen as the bookends supplying the foundational knowledge, skills and understanding that allow Technology as digital and design and Engineering to flourish. Does this detract from the contributions S and M can make? How different would it be if METS or SMET was the acronym used? How significant is it that in STEM, Science is placed first and Mathematics placed last? In so doing was it assumed that from past experiences Science was the natural leader of new initiatives? Does the placement of Mathematics last explain why some with expertise in mathematics have been reluctant to engage in discussions about STEM education? Given previous similar acronyms such as STS (1990s) in Australia and SET in the UK (2002) where mathematics was conspicuous by its absence, will its inclusion ensure STEM education is more successful than its predecessors? Given that both technology and engineering include a design process, how different are these?

What about the relationship between curriculum, pedagogy and assessment in STEM education? From my experience of working with stakeholders in developing and reviewing curriculum, agreement as to what should be included or excluded rarely runs smoothly nor are decisions made unanimously. Discussions and debates as to what content would be included, which assessment practices are most appropriate and whether particular pedagogical practices are preferred for STEM education programs are likely to be similarly dynamic.

When considering where the findings from this study may lead, I reflected on the outcomes of the *Report of the Committee of Inquiry into Labour Market Programs* (1985) often referred colloquially to as the Kirby report and its relationship to STEM education. This report investigated the changing nature of the labour market and future employment opportunities and the kind of skilled and qualified workforce that this would require. It also concerned itself with increasing the participation in education and training beyond secondary schooling among previously underrepresented groups in the community. The report also identified that ensuring continuing Australia's economic growth and prosperity was

dependent on reforms in education leading to, for example, the introduction of vocational education and training programs in secondary schools. Many of the issues investigated in this report are similar to those associated with STEM education so perhaps it is timely to revisit the recommendations included to determine if any of these are applicable to STEM education.

The report argued that, in order to adapt to changing labour markets, Australia needed a specifically skilled and qualified workforce to ensure continuing economic growth and prosperity. This could be likened to the context (increasing globalisation and use of technologies) in which STEM education was introduced and the type of knowledge and skills needed for careers and employment in STEM and STEM related fields. The report also recommended that reforms should be long-term with sustained flexibility to adapt to changing circumstances. Of equal importance was monitoring any initiative implemented that was part of the reform and the provision of time to revisit and reshape the initiative as required. An example of monitoring a STEM education initiative is measuring the increase in participation of students in senior secondary mathematics and science subjects as a result of STEM programs in primary or lower secondary education and if changes are required to these programs.

The report moved beyond its initial remit to undertake a more comprehensive investigation that looked beyond the immediate or quick fix solution and instead focussed on the long-term implications of new initiatives. Such an approach has implications for STEM education. For example, if increasing the participation of students in senior secondary mathematics and science subjects is an accepted and desirable outcome of STEM education, are there sufficient opportunities for these students to continue their studies at a tertiary level or to find employment in STEM or STEM related occupations? This is an example of the long-term view where the report provided a vision for the reforms that was grounded in the present and looked to the future.

The integrated use of the three methods in this study could be useful in research that sought to understand differences and similarities in opinions amongst participants rather than seeking consensus. The same approach may be useful if an assessment lens or pedagogical lens was used to interrogate STEM education policies and programs or with to determine how practising teachers tasked with implementing STEM education understand it.

## 7.11 Conclusion: What are the challenges for STEM education in the Australian context?

This study suggests that it may be possible to construct more than one vision for STEM education in the Australian context. The reasons given by the participants in this study to support the choice and implementation of the visions were diverse and reflected how they conceptualised STEM education. However, there were similarities in how the participants conceptualised STEM education and this was evident when the same reason was given to support a particular choice of vision and its implementation. This raised the possibility that different visions could coexist, where one vision may be more suitable than the others to a particular local context. As this study showed, what is important is that any vision constructed for STEM education in the Australian context should be aspirational and applicable to the education of all young Australians. As argued by some participants, any vision developed also needs to be clear, purposeful and coherent. Such visions should also be able to accommodate the diverse conceptualisations of STEM education that this study showed existed in a particular local context.

As this study also suggested there is no one agreed vision for STEM education in the Australian context. What this study found is that conversations are required involving all those invested in STEM education about what it is expected to achieve and what it offers at the local, national or global level. In this study, the findings from the document analysis, Delphi study and semi-structured interviews pointed to tensions between the achievements expected and the possible opportunities for STEM education in the Australian context. The integrated use of these three different methods enabled the tensions to be identified and provided new, multi-perspective insights into how these would likely impact on the challenges facing STEM education in the Australian context.

I believe these tensions were due in part to how different people have conceptualised STEM education and this has produced three challenges for STEM education in the Australian context. First is to understand how people conceptualise STEM education and how this may impact on how they approach its implementation. This would include accepting and respecting any differences in these conceptualisations between a group of people working to develop and implement STEM education programs.

The second challenge is to establish and sustain collaborative partnerships that include those interested in STEM education to design curriculum, assessment and pedagogical

practices and programs to implement STEM education that are inclusive of all students regardless of ability or gender or ethnicity or location. The establishment of STEM education centres in the UK and Singapore could serve as a model for possible partnerships that bring together educators, students and their families, business, industry and governments in Australia.

The third challenge is the use of local contexts and issues to develop the knowledge, skills and understanding that then can then be used to investigate global issues within an accountability framework where student achievement is measured against set standards or on national and international testing programs. This will require innovative approaches in curriculum development and in assessment and pedagogical practices that engage students and provide access and equity of access for all young Australians. I believe this provides important evidence that a national STEM curriculum is not required. Instead what is required is the development of local STEM education programs that are relevant and appropriate for students and their community that will enable them to act locally and influence globally as informed citizens capable of managing future challenges.

Meeting these challenges will require a coherent and explicit strategy for the implementation of STEM education in the Australian context similar to that recommended by the NAE & NCR (2014) and in the findings in the Delphi study and the semi-structured interviews (as discussed in 7.9).

This study shows that addressing these challenges requires a shift in the type of questions being asked is required. Rather than a focus on questions such as what content should be included or should the approach be interdisciplinary, questions that take a big picture view should be asked first and would set the direction for implementation. To achieve this the following questions will need to be asked and investigated:

- Should STEM education be included in the education of all young Australian? Why or why not?
- If STEM education is included, at what year levels? Why and how?
- What will be required to implement, sustain and evaluate the implementation of STEM education?
- Will providing students with STEM education learning experiences that are relevant to them and their future and better engage them with their learning?

- Does providing a general or liberal education better equip all students to participate in and contribute to a STEM driven economy?

The focus of STEM education in the Australian context is to generate and support continuing economic and social prosperity for all Australians now and into the future. As such, it as has placed the spotlight on the provision of a high-quality education accessible to all young Australians. This presents challenges for STEM education in the Australian context that are complex and similar to those of other countries.

Perhaps as we enter the third decade of the twenty-first century it is timely to ask:

*What does a high-quality STEM education for all young Australians look like?* and

*How does this fit within a high-quality education system for all young Australians?*

In undertaking this study, one participant drew my attention to the complexity of education but suggested that this does not mean that education reforms are also complex:

> Gosh there's so much I still don't understand about the business of education and science education. And yet, on the other hand, in some ways it seems so obvious and so simple. And yet we seem to make it so complex. It shouldn't be so complex.

I believe this study has broader implications for education beyond the introduction and implementation of STEM education. For example, the investigation of whether the current practices in curriculum development, assessment and pedagogy are suitable to implement new initiatives in education that are relevant to the future of all young Australians or if more innovative practices are required. Determining what all young Australians will require from their education to become confident, resilient and informed citizens who contribute to Australia's future prosperity should be a priority for further research in education.

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# Appendices

## Appendix 1 The list of documents analysed in Chapter 4

### Government: International

- Department of Education (USA) (2016): *STEM 2026 A Vision for Innovation in STEM Education.* Office for Innovation and Improvement.*
- HM Treasury (2002): *SET for success-the supply of people with science, technology, engineering and mathematics skills*. *The report of the STEM Review*.*
- National Academy of Engineering and National Research Council (NAE & NCR 2014): *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. Washington. DC: The National Academies Press.
- National Science and Technology Council (2013): *Federal Science, Technology, Engineering and Mathematics (STEM) Education.*
- NGSS Lead States (2013): *Next Generation of Science Standards: For States, By States*.

### Government: Australian

*Commonwealth*

- Australian Curriculum Assessment and Reporting Authority (ACARA) (2019): Australian Curriculum (AC).*
- Australian Research Council (ARC) (2015): *National Science and Innovation Agenda.*
- Chubb, I. (2013a): *Science, Technology, Engineering and Mathematics in the National Interest: A Strategic Approach.* (Office of the Chief Scientist).*
- Education Council of Australia (ECA) (2015): *National STEM School Education Strategy.* A comprehensive plan for Science, Technology, Engineering and Mathematics Education in Australia 2016-2026.*
- Education Council of Australia (ECA) (2015): *National STEM School Education Strategy.* A comprehensive plan for Science, Technology, Engineering and Mathematics Education in Australia 2016-2026.
- Finkel, A. (2016a): *Australia's STEM Workforce. Science, Technology, Engineering and Mathematics*.
- Siekmann, G. and Korbel, P. (2016): *Defining 'STEM' skills: review and synthesis of the literature.* Support document 1 (NCVER).*

*States/Territories* (included statutory authorities)

- Department of Education (New South Wales 2018): *STEM.*
- Department of Education (Queensland 2013): *A Strategy for STEM in Queensland state schools.*

- Department of Education (Queensland 2013): *A Strategy for STEM in Queensland state schools.*
- Department of Education and Training (2016): *VicSTEM Science, Technology, Engineering and Mathematics.* STEM in the Education State.*
- Education Standards Authority New South Wales (2017): *Learning for the Future and Leading STEM*.

**Research**

- Australian Research Council (ARC) (2015): *National Science and Innovation Agenda.*
- Brower, T., Grimsley, R. and Newberry, P. (2007*): STEM is Not Just a Four Individually Lettered Word.*
- Hudson, P., English, L., Dawes, L., King, D., & Baker, S. (2015*):* Exploring Links between Pedagogical Knowledge Practices and Student Outcomes in STEM Education for Primary Schools.
- National Research Council (NCR) (2012): *A Framework for K-12 Science Education Science Education Practices, Crosscutting Concepts and Core Ideas.*
- NGSS Lead States (2013): *Next Generation of Science Standards: For States, By States*.
- Rosicka, C. (2016): *From concept to classroom Translating STEM research into practice. From concept to classroom Translating STEM research into practice* the Australian Council for Educational Research (ACER)*

**Professional associations**

- Engineers Australia (2017): *Engineers Make Things Happen. The need for an engineering pipeline strategy summary report.**
- Royal Academy of Engineers (RAE) 2016: *The UK STEM Education Landscape* prepared by R. Morgan and C. Kirby

**Business/industry**

- Australian Advanced Manufacturing Council (AAMC) (2016): *STEM Guide Aiding Australia's Next Gen of Innovators for inclusion in the SPI 2016 – STEM Programme Index.*
- Deloitte Access Economic (DAE) (2014): *Australia's STEM workforce: a survey of employers.* (prepared for Office of the Chief Scientist)
- PricewaterhouseCoopers (PwC) Australia (2016): *Practical steps to improve the quality of science and mathematics teaching in primary schools. Making STEM a primary priority.**
- Prinsley, R. and Baranyai, K. (2015): *STEM Skills in the workforce: What do employers want.* Occasional Paper Series. Issue 9.

**Philanthropic**

- Hobbs, L., Jakab, C., Millar. V., Prain, V., Redman, C., Speldewinde, C., Tytler, R., & van Driel, J. (2017). *Girls' Future - Our Future. The Invergowrie Foundation STEM Report.* *

**Other**

- Cunningham, W. V. and Villaseñor, P. (2016): Employer Demands, and Implications for Public Skills Development Policy Connecting the Labour and Education Sectors. (The World Bank).*
- UNESCO Education Sector (2017): *Cracking the code: girls' and women's education in science, technology, engineering and mathematics (STEM)*.

* denotes the analysis of documents that is presented in 4.1.

## Appendix 2 The three questionnaires from the Delphi study

### Delphi study: First questionnaire

When completed please return to **Ann Osman** osman.a@unimelb.edu.au **by 13 May 2018**

Q1What do you believe is the purpose(s) of 'STEM education'?

Q2Given the purpose(s) of STEM education you identified in Q1 what is necessary/required to achieve/implement this purpose(s)?

Q3How would you explain STEM education to someone who is not familiar with this term?

Q4 Any additional comments

Thank you for your participation.

Ann Osman

**Delphi study: Second questionnaire**

When completed please return to **Ann Osman** osman.a@unimelb.edu.au **by Friday 8 June 2018**

Delphi Study: Questionnaire 2

**Q1.** Responses to Q1 on the Questionnaire 1 (the purpose(s) of STEM education) have been collated to form the list below. Please rank these from 1 to 6 where 1 is the most important for you and 6 is least important for you.

The purpose of STEM education is to

☐ equip people with the knowledge and skills necessary to drive economic and social prosperity in the 21st Century technology rich workplaces and careers.

☐ build students' understanding of the world around them and how they can contribute to making it a sustainable place to live now and into the future.

☐ provide pathways for entry into the digital workforce and for the next generation of specialists in STEM fields.

☐ engage students with 'real-world problems' that require input from each of Science, Technology, Engineering, and Mathematics to solve.

☐ improve access to careers in STEM fields for previously under-represented groups (for example girls/women, rural, indigenous).

☐ introduce students to the use of evidence to make ethical decisions about contemporary and complex issues.

The reason(s) for my ranking is:

**Q2.** Responses to Q1 on Questionnaire 1 (requirements for the implementation of STEM education in the Australian context) have been collated to form the list below. What level of priority, if any from 1 (highest) to 5 (lowest), would you assign to each one? Space has been provided for you to elaborate on your responses.

| **Requirement for implementation for STEM education** | **Priority** | **Elaboration** |
|---|---|---|
| A shift from a focus of acquiring specific content knowledge to the achievement of outcomes where acquisition of skills has a greater importance in the development of curriculum and assessment tasks. | | |
| Sustainable partnerships between schools, universities, TAFEs and industry/business as applicable that support and collaborate on the delivery of high-quality STEM education in schools. | | |
| Use of age appropriate applied investigations and activities to demonstrate how knowledge and skills from multiple disciplines are used to solve problems. | | |
| Develop a transdisciplinary approach to teaching and learning that incorporates the elements of STEM disciplines and draws from other disciplines as required to investigate issues important to students/community | | |
| Development of a curriculum for Early Years to Year 12 that links learning areas (disciplines) in ways that support students to solve 'real-world problems'. | | |
| Building community understanding of the relationship between studying STEM subjects and future employment including supporting parents to become STEM aware. | | |
| Review of assessment requirements of senior secondary STEM subjects to accommodate projects completed using an inter-disciplinary approach | | |

**Q3** Any additional comments

Thank you for your participation.

Ann Osman

**Delphi Study: Questionnaire 3**

**Please return to Ann Osman** osman.a@unimelb.edu.au **by 17 July 2018**

Q1. Three potential visions for STEM education in the Australian context are presented below. These visions have been constructed from the analysis of data provided in response to Questionnaires 1 and 2.

Which vision best aligns with YOUR preferred vision for STEM education in the Australian context?

1. STEM education contributes to a broad suite of learning experiences that enable all young people to participate in and contribute to building sustainable communities.
2. STEM education provides the skills that enable all young people to contribute to growing the nation's economy and global competitiveness.
3. STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they live now and into the future.

My preferred vision is No. _____

I chose this vision because

Is there anything you would like to add to or delete from this vision?

**Q2.** To implement my preferred vision, it is pivotal …

To complete this sentence please tick up to three of the statements listed below and provide reason(s) for your choice.

These statements have been constructed from the analysis of data provided in response to Questionnaires 1 and 2.

In addition to the three selected, a space has been provided for you to construct your own statement if required.

| Statement | √ | Reason(s) for choice |
|---|---|---|
| the curriculum for STEM education accommodates the development of knowledge and skills within each discipline and across the disciplines of STEM. | | |
| the assessment practices for STEM education focus on the application of knowledge and skills to identify and solve 'real world' problems. | | |
| the pedagogical practices used to deliver STEM education inspire young people to choose STEM-related subjects at school and to pursue these into higher and/or further education and careers. | | |
| ongoing high-quality professional learning for teachers is provided that increases their competence and confidence (and experiences) in delivering STEM education. | | |
| implementation of STEM education is coordinated to maintain high-quality and consistency across jurisdictions. | | |
| informed communities actively support young people to consider pursuing STEM subjects, careers or employment. | | |
| employment opportunities are available that are attractive to young people who are job capable in STEM and STEM related fields. | | |
| Own statement (not more than 25 words) | | |

**Q3** Additional comments

This questionnaire concludes the Delphi study.

Thank you for your participation in the Delphi study.

I look forward to continuing the conversation about STEM education in the Australian context in our upcoming interview

Ann Osman

## Appendix 3 Interview questions asked of the Delphi study participants

### Interview questions for Participant A

- How would you like to be described as a participant in this research? (in 25 words or less).
- Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.
- Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.
- Why is STEM education an 'ambiguous' term? Why has the acronym STEM (Education) garnered such popularity despite the lack of a clear understanding of it purpose and implementation?
- What will assessment and pedagogical practices look like in STEM education that includes both disciplinary and interdisciplinary perspectives?
- There have been past attempts at shared commonwealth and state co-ordinated implementation of programs (for example national profiles and the Australian Curriculum) with varying levels of success. What would it take for the implementation of STEM education be more successful and sustainable?
- From Questionnaire 3 is there a need for 'STEM literacy' that builds on and from scientific literacy? Does STEM education then mean developing young people's STEM literacy?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Any other comments

### Interview questions for Participant B

- How would you like to be described as a participant in this research? (in 25 words or less).
- Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.
- Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.
- As this participant worked with Garth Boomer during 1980s I plan to ask a question about how Participant B believes Boomer's ideas influenced and shaped curriculum

development and if these 'live on' in the Australian Curriculum. (A similar question would also be appropriate for Participant P). This is related to giving the curriculum development framework a direct link to the Australian context.

- From Questionnaire 1, is there value in shifting from content as the goal to process skills? Why?
- From Questionnaire 2, how do we stop STEM education '*setting back what has been achieved in science education'?* Related to q8 below
- From the choice of vision (Vision 1 from Questionnaire 3), how does Education reclaim a leadership position in driving education reform given the highly political nature of education and the current economic climate?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Any other comments.

**Interview questions for Participant C**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.
- Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.
- What do mean by an 'integrated' approach to STEM education?
- On Questionnaires 2 and 3 you mentioned '*quantitative critical literacy*' what does this term in relationship to STEM education?
- Does the use of terms such as *integrated or multidisciplinary or transdisciplinary or interdisciplinary* approaches to STEM education shift the focus of teaching and learning from the acquisition and application of knowledge to development of a set of specific skills?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Any other comments

**Interview questions for Participant D**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.
- Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.
- Given the current political and economic environment how can educators reclaim the leadership of the development, implementation and evaluation of education programs such as STEM education?
- From Questionnaire 3, what will it take to engage teachers in professional conversations (and what would these look like) as to how best to prepare students to become '*socially responsible, well-informed and highly capable citizens*'?
- By identifying the many versions of the STEM acronym where areas are added (for example STEAM and STEMM …) as educators, are we further 'overcrowding' the curriculum or attempting to streamline so that everything revolves around S, T, E, M?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Any other comments

**Interview questions for Participant E**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.
- Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.
- In Questionnaire 1 you mentioned '*increasing community participation in STEM subjects for general enjoyment and well-being including to support hobbies'*- Does this imply that not all people will want to pursue careers in STEM related fields? Is this pointing towards a belief that *STEM education is for all* up to a particular level (a

bit like the previous push for 'science for all' up to Year 10? How does this sit with jobs of the future requires STEM skills?

- In elaborating on your choice of vision from Questionnaire 3 you mentioned the '*breadth/enabling benefit of STEM education'*- what do you mean by breadth? Is this part of q4 above?
- Will STEM education be around in 5 or 10 years? If so what would it look like? How will we judge the success or otherwise of STEM education? How will the vision you selected on the third questionnaire accommodate this?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Any other comments

**Interview questions for Participant F**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.
- Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.
- From Questionnaire 1, what are the expectations and aspirations of the STEM movement that should be included in 'foundational studies' in science and mathematics? How would this make these subjects more relevant to students and society? Would this lead to an 'overcrowded curriculum' in these disciplines?
- What happens at Years 11 and 12?
- If 'integrated units' were to be provided what type of academic rigour would be required to prevent the past mistakes (from Questionnaire 1)
- From Questionnaire 3 is there a need for 'STEM literacy' that builds on and from scientific literacy? Does STEM education then mean developing young people's STEM literacy?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Any other comments

**Interview questions for Participant G**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.
- Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.
- In Questionnaire 2 you mentioned a '*tendency to under-estimate the need to acquire knowledge and understanding of specific types of content'*- who should select this? Is this suggesting context independent or context dependent? How should it be expressed in curriculum documents? For example, as outcome statements/standards …
- Like you several other participants were also concerned with rhetoric associated with STEM education and the subsequent exclusion of the Humanities (and The Arts). How do we ensure the future of these areas?
- From Questionnaire 3, you mentioned the relationship between assessment practices that focus on applications and problem solving bring an interdisciplinary approach was '*important if the 'E' for engineering is to be taken seriously'.* How do you define 'interdisciplinary? Why would this ensure *'E'* is taking seriously?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Any other comments

**Interview questions for Participant H**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.
- Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.
- From Questionnaire 1, what level of mathematics do you think the whole community needs? Does this relate to the level of mathematics all primary teachers should have? Does it also include how mathematics is taught at schools?

- Would this be reflected in a shift in attitudes towards mathematics by students, parents and the wider community?
- As this participant was the only one who selected Vision 2, I want to unpack and further explore the reasons for the choice.
- From Questionnaire 3 your chose Vision 2. Will the acquisition of STEM skills be independent of a set of knowledge or does it represent a shift from a focus purely on knowledge (Questionnaire q 2 referred to 'too much emphasis on rote learning')? Will any necessary knowledge be developed on the 'job'?
- Will the skills be developed in particular contexts?
- What are the likely implications for curriculum and assessment of this shift in emphasis from knowledge to skills?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Any other comments

**Interview questions for Participant L**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.
- Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.
- From Questionnaires 1 and 2, you expressed concern about the Humanities in light of inclusion of 'STEM education' programs in schools. How might the Humanities retain their place in school education?
- Professional learning/development for teachers featured prominently in your responses to all three questionnaires. What would you like this to look like/include? Who and how might it be best delivered?
- In Questionnaire 3 you '*believed that it is important to learn* the *knowledge of each of the STEM disciplines'.* What would this knowledge look like? Would it be linked with particular skills and/or contexts?

- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Any other comments

**Interview questions for Participant P**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Do you feel your ideas about STEM education have changed as a result of participation in the Delphi study? Please elaborate.
- Is there a question that should have been asked in any of the questionnaires in the Delphi study? Please elaborate.
- As this participant worked with Garth Boomer during 1980s I plan to ask a question about how Participant P believes Boomer's ideas influenced and shaped curriculum development and if these 'live on' in the Australian Curriculum. (A similar question would also be appropriate for Participant P). This is related to giving the curriculum development framework a direct link to the Australian context.
- On Questionnaire 2 you saw yourself as an 'outlier'*STEM not helpful, almost misleading acronym*- you reinforced this in Questionnaire 3. Why?
- What will it take to achieve the 'significant investment in both pre-service and in-service professional development' you mentioned on Questionnaire 2?
- On Questionnaire 3 you chose Vision 3 as 'it is the most ambitious scope…'. Why is scope of a vision for STEM education important?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community? (May not be necessary as could be included in response to q6 above
- Any other comments

## Appendix 4 Interview questions specific to each Non-Delphi study participants

### Interview questions for Participant M

- How would you like to be described as a participant in this research? (in 25 words or less).
- Why do you think 'STEM education' is gaining so much attention now?
- What are implications for Technology and Technology Education in this time of STEM education?

The next question looks at the visions from Delphi study Questionnaire 3. The participants will be provided with a copy of the visions.

- Which of these visions is your preferred vision (best matches/aligns with yours)? Please elaborate. Do the purposes you have for STEM education fit with the vision?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Will STEM education be around in 5 or 10 years? Why? If not, what will have replaced it?
- If STEM education is (or is to be) the answer, what is the question? If it is not the answer then what should the question be?
- Any other comments

### Interview questions for Participant R

- How would you like to be described as a participant in this research? (in 25 words or less).
- Why do you think 'STEM education' is gaining so much attention now?
- What are implications for gender and equity of access in this time of STEM education?
- The next question looks at the visions from Delphi study Questionnaire 3. The participants will be provided with a copy of the visions.
- Which of these visions is your preferred vision (best matches/aligns with yours)? Please elaborate.
- Do the purposes you have for STEM education fit with the vision?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?

- Will STEM education be around in 5 or 10 years? Why? If not, what will have replaced it?
- If STEM education is (or is to be) the answer, what is the question? If it is not the answer then what should the question be?
- Any other comments

**Interview questions for Participant S**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Why do you think 'STEM education' is gaining so much attention now? Was there a specific event that precipitated business interest in and commitment to STEM education?
- How do you explain STEM education to non-STEM people?
  The next question looks at the visions from Delphi study Questionnaire 3. The participants will be provided with a copy of the visions.
- Which of these visions is your preferred vision? Please elaborate.
- Do the purposes you have for STEM education fit with the vision?
- How will we know that STEM education is achieving its purposes? Are the 21st century skills only achievable through STEM? How different are these skills to those required 100 years ago? Have the skills changed or is it the 'tools' we use to develop and implement these skills that have changed (or emerged)?
- If STEM education is (or is to be the answer) what is the question? If it is not the answer then what should the question be?
- From your past experiences/current position, what one piece of advice related to STEM education would you provide to the community?
- Any other comments

**Interview questions for Participant T**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Why do you think 'STEM education' is gaining so much attention now?
- What are implications for research in this time of STEM education?
  The next question looks at the visions from Delphi study Questionnaire 3. The participants will be provided with a copy of the visions.

- Which of these visions is your preferred vision (best matches/aligns with yours)? Please elaborate.
- Do the purposes you have for STEM education fit with the vision?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Will STEM education be around in 5 or 10 years? Why? If not, what will have replaced it?
- If STEM education is (or is to be) the answer, what is the question? If it is not the answer then what should the question be?
- Any other comments

**Interview questions for Participant X**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Why do you think 'STEM education' is gaining so much attention now?
- What are implications for mathematics and mathematics education in this time of STEM education?

  The next question looks at the visions from Delphi study Questionnaire 3. The participants will be provided with a copy of the visions.
- Which of these visions is your preferred vision (best matches/aligns with yours)? Please elaborate.
- Do the purposes you have for STEM education fit with the vision.
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Will STEM education be around in 5 or 10 years? Why? If not, what will have replaced it?
- If STEM education is (or is to be) the answer, what is the question? If it is not the answer then what should the question be?
- Any other comments

**Interview questions for Participant Y**

- How would you like to be described as a participant in this research? (in 25 words or less).
- Why do you think 'STEM education' is gaining so much attention now?

- What are implications for philanthropic organisations that support equity of access and inclusion in education in this time of STEM education?

  The next question looks at the visions from Delphi study Questionnaire 3. The participants will be provided with a copy of the visions.
- Which of these visions is your preferred vision (best matches/aligns with yours)? Please elaborate.
- Do the purposes you have for STEM education fit with the vision?
- From your past experiences and current position, what one piece of advice related to STEM education would you provide to the community?
- Will STEM education be around in 5 or 10 years? Why? If not, what will have replaced it?
- If STEM education is (or is to be) the answer, what is the question? If it is not the answer then what should the question be?
- Any other comments

## Appendix 5 Additional information provided to the Non-Delphi study participants

1. STEM education contributes to a broad suite of learning experiences that enable all young people to participate in and contribute to building sustainable communities.

2. STEM education provides the skills that enable all young people to contribute to growing the nation's economy and global competitiveness.

3. STEM education equips all young people with the knowledge and skills required to understand the complex and challenging nature of the world in which they live now and into the future.