Opening up pathways:
Engagement in STEM across the Primary-Secondary school transition

A review of the literature concerning supports and barriers to Science, Technology, Engineering and Mathematics engagement at Primary-Secondary transition.

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Education is becoming increasingly important to young peoples’ success in an information-rich world. Developing in young Australians sophisticated knowledge and ability in Science, Technology, Engineering, and Mathematics (STEM), and building Australia’s capacity, capability and strength in science, technology and innovation will enable the nation to meet the new and taxing demands in the 21st century. STEM skills and knowledge will be essential to meeting the challenges of the new century, through scientific advances, technological innovation, and mathematics as a tool underpinning these.

The present report undertakes a comprehensive review of the literature on the barriers and supports that young people encounter in pursuing studies in STEM disciplines in Australia. It draws together and reviews literature across a variety of disciplines on trends in STEM participation in Australia and globally, and investigates existing and ongoing research and literature on the reasons why people either continue or discontinue study and employment in STEM related fields. This review focuses primarily on the issue of transition, examining specifically changes and continuities in attitudes to STEM subjects as students make the transition from primary to secondary school, and from the middle to upper secondary school years. It identifies issues bearing on student pathways in STEM, profiles the existing STEM workforce, and describes broad trends in engagement in STEM in Australia.

The review focuses on the issues surrounding STEM prioritisation, participation, and demand. It considers barriers to STEM pathways, and explores current understandings of the attitudes and aspirations that affect people’s participation in STEM related fields. The intention is to assist policy makers in determining significant points where interest or participation in STEM declines and the factors shaping this, and in designing interventions, and allocating resources appropriately across potential areas of intervention. The review considers the available research regarding policy focus, and observes a number of international policy directions that may successfully raise the level of STEM participation and foster more positive attitudes towards school-level STEM education in Australia.

In conducting a broad review of the literature concerning demand in STEM occupations, it has become clear that predicting demand depends on accurate knowledge of a range of economic and social factors such that it is difficult to be definitive about future needs. Indeed, there is disagreement about the real levels of current and future demand, and a need for further research in this area. Nevertheless, there are identified shortages in specific areas of engineering and technology, at a range of professional levels, and increasing concern among industry and professional bodies that Australia has a serious STEM skills shortage. There is clear evidence of declining participation in higher-level mathematics and the physical sciences at upper secondary and tertiary level, and a current and looming crisis in the supply and quality of teachers of mathematics and science. The review takes the position that while the metaphor of a leaky pipeline is useful as the basis of an exploration of factors affecting engagement in and choice of STEM subjects and subsequent careers, it imposes serious restrictions on consideration of broader issues relating to STEM in Australia. These include (a) capacity
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building to support innovation and policy directions in STEM, demanding increased capability in mathematics and science across a wide spectrum of the population; (b) an acknowledgment of multiple pathways through which people might enter or leave STEM related work; and (c) the importance of representing, in school, mathematics and science and technology as important aspects of contemporary culture, beyond their immediate economic implications.

The review found considerable evidence that, for the majority of students, their life aspirations are formed before the age of 14, with the implication that engaging students in STEM pathways becomes increasingly difficult after the early secondary school years. Interventions and resources aimed at encouraging student engagement in STEM thus need to be prioritized to engage and capture the imagination of students in the upper primary and early secondary school years. Student aspirations are significantly mediated through the secondary school years and transformed into career choices later by a range of factors including interest and self-efficacy in relation to mathematics and science, parental expectations and encouragement, teacher support and inspiration, career expectations and exposure to career guidance, exposure to role models and successful adults, and perceptions of the usefulness of the subject. These factors differ in importance and aspect for mathematics compared to science, and for developmental level and gender.

Students’ responses to STEM are usefully framed by the concept of identity. There is evidence that identity formation for youth in late modern societies, such as Australia, is focused more strongly on self realisation, and contributing to the future. It is argued that school mathematics and science need to move away from their instrumentalist emphases and value free presumptions if they are to capture the imagination of young people. For any cohort of students there is a wide range in the fundamental perceptions of and responses to schooling and to mathematics and science. These are particularly apparent in relation to gender, and cultural and racial factors, but there is wide variation beyond this. In developing strategies to tackle the decline in student interest, it is important to be aware of the complexity and changing nature of students’ attitudes towards school and their readiness to engage with STEM and be motivated in learning. This implies the need to develop for students an array of options for engagement, and re-engagement with STEM education.

In reviewing responses of students to mathematics and science, it is clear that implemented curricula and pedagogy in Australia fail to engage students adequately in these subjects, and thus in STEM. For mathematics and science there are two common, broad themes that emerge from the literature. The first is that of self-efficacy and the importance of encouragement and success to enlist students’ continued engagement in mathematics and science. In the mathematics literature the constructs of resilience and optimism are valuable concepts for analysing the needs of students and hence the need to support teachers to develop more powerful pedagogies that support and encourage students. For mathematics, the development of problem solving capabilities, and for science, engagement in investigative processes, are significant curriculum innovations that are capable of engaging students, with appropriate pedagogical support. The second theme, which is more strongly represented in science but is also significant for mathematics, is that of relevance and the need to engage students in science and mathematics that links with their lives and interests and broader aspirations. Our findings suggest the key to student engagement lies not so much in the nature of subject content, but rather with pedagogy. In both
mathematics and science the prevailing pedagogies are restricted in focus and flexibility. There is a need to promote more varied pedagogies that challenge, support and interest students, as well as engaging them with authentic and contemporary issues and problem solving in STEM that strengthen the intellectual rigor of STEM learning and interest students in STEM content.

The range of possible pathways into STEM is restricted as some students are denied opportunities to continue with relevant mathematics courses, thus closing off options. There is also a significant issue concerning difficulties experienced with transition from primary to secondary school, in terms of diminishing levels of personal support at a time when subject difficulty increases rapidly, and content becomes more formally structured. Opportunities are closed off by a lack of awareness of articulated pathways into tertiary courses and subsequent careers opened up by higher-level mathematics and physical science, or of pathways through further education. In primary school in particular, students have a limited and often erroneous appreciation of the nature of work in STEM, and of the human aspects of this work – the extent to which STEM careers involve working with people and the extent to which they serve humanity. Valuable interventions would include: widening students’ horizons and options by promoting a realisation of the diversity within STEM, with a particular focus on developing a better knowledge of possible careers in, and from mathematics and science and technology; improving career guidance, including better understanding of vocational education pathways; and emphasising the human and socially beneficial aspects of STEM work.

Lack of visibility of mathematics and science as human endeavours has impacted on students’ career aspirations and disengaged those (including many girls) who prefer collaborative practices focused around solving problems to improve communities rather than competitive practices where the answer is the focus. Low enrolments in mathematics and the physical sciences by girls at the tertiary level compared to their participation in tertiary education overall reflects the clinical rather than human nature of the way many of these STEM subjects are presented. Although the gap between the performances of girls and of boys has narrowed over time, there are still substantial issues to address around recognising individual differences between students and increasing the pedagogical practices known to intellectually engage all students, including girls, in STEM. These practices include collaboration, inquiry, group work, and a diversity of assessment practices.

Further, there is a significant lack of knowledge about STEM in the community. Early findings from pilot programs in Australia, the UK and the US to raise the level of community awareness of STEM are promising. These have focussed on developing positive media images of STEM professionals, and promoting further links between schools, industry and community. A productive direction for support and intervention that is gaining momentum in Australia, is the development of links between schools and outside institutions such as community and government groups or industry or universities, that can offer young people better representations of what STEM professionals do, and what STEM practice is, through innovative curriculum practices supported by expanded resources.

The finding that pedagogy is the critical element in enlisting student engagement with mathematics or science aligns with well established findings that the quality of classroom teaching is the most significant factor in
student learning and engagement. Teachers are highly valuable resources in STEM education. There is a pressing need to recruit good quality applicants into teacher education courses, primarily by ensuring that the STEM teacher workforce is well compensated and supported. Prominence needs to be given to developing best practice approaches to teacher professional learning that focuses on pedagogies that engage students in mathematics and science. This needs to be research based. There is evidence that, for this to make a difference, teachers need to be supported within the school to develop the knowledge and skills to significantly shift their practice and also to take advantage of technological changes in advancing learning.
1 Introduction

Our world today is shaped by a constant flow of information, the emergence of new technologies, and movements of people within and between nations. Large numbers in the community are driven by the desire to live healthily, to reduce their carbon footprints, and to ensure the sustainable living on our planet. In this climate, nations are increasingly concerned to develop and maintain their technological and industrial capacity in the face of competition in the global economy. Fostering and developing the creativity and problem solving abilities of young Australians is fundamental to promoting innovation and rising to the challenges of the 21st century. In order to survive and thrive in the world tomorrow, young people will need a broad range of knowledge and skills, including in science, technology, engineering, and mathematics.

This review examines supports and barriers to school level engagement in Science, Technology, Engineering and Mathematics (STEM). Its brief is to focus on engagement at the Primary-Secondary transition, which is taken to mean across those years from upper primary school through what are known as the middle years of schooling, to the point where students make their subject choices into the senior schooling years.

1.1 Background to this review

Considerable attention has been given in recent years to the low levels of student engagement in STEM related study and occupations. This concern has found its expression in a number of high level reports and initiatives, which paint a disconcerting picture of decline in participation across OECD countries.

The Australian Government has in recent years produced a number of reports concerning participation in STEM occupations, and the need to improve science and mathematics education provision and teaching quality. These include the recent audit of skills, and the earlier report Backing Australia’s Ability (DEST, 2003). These have given rise to a number of high profile initiatives such as the Boosting Innovation Science Technology and Mathematics Teaching (BISTMT) program (DEST, 2005b) which included the Australian School Innovation in Science, Technology and Mathematics (ASISTM) project (see Tytler, 2007b for an account of this project), and the Primary Connections program (Australian Academy of Sciences, 2005). At government level, there is substantial concern that the decline in student uptake of post-compulsory STEM study in Australia restricts the development and expansion of science- and technology-based industry and compromises Australia’s capacity to maintain a sufficient market share in these key areas.

A report by the US academies of sciences, engineering, and the institute of medicine (COSEPUP, 2005) highlights the importance, and high level, of demand for science professionals in post-industrial societies. In the US, the Science and Engineering share of total civilian employment has grown from 2.6% to 3.8% over the years 1983 to 2002, yet the training of STEM professionals needed to fuel this growth has not kept pace. The US Bureau of Labor Statistics projects that by the year 2014 the
combination of new positions and retirements will lead to 197,000 openings in the life and physical sciences, 507,000 engineering positions, and over 1.3 million jobs in computers and mathematics (Bureau of Labor Statistics, 2005, cited in Maltese, 2008). The flat growth in core STEM fields of education, combined with the age profile of scientists, a large number of whom are near retirement age, means that the US cannot rely on locally produced STEM workers to fulfil these requirements.

The COSEPUP report identified the competitive international climate in science-based industries as the core issue, and highlighted the high level of growth in developing countries in the STEM area. The report compared the number of engineers graduating annually from the USA, with China, observing that China graduated more than eight times the number engineers annually. The report also compared the decline of chemical companies in the USA to the increased rate construction of chemical plants in China. These US figures are also relevant to Australia, which produces fewer engineers per head of population than other OECD countries (Victorian Parliament Education and Training Committee, 2006).

The European Commission report (High Level Group on Human Resources for Science and Technology, 2004), ‘Europe needs more scientists’, also highlighted the importance of maintaining and increasing the supply of STEM capable researchers and developers for driving a technologically competitive Europe. This report identified problems with school science education as the underlying problem, arguing that school science should better represent real science practice, and cater more effectively for the needs and interests of young people. Countries that appear to do well, in terms of scientific literacy among young people and numbers of people employed as scientists, were found to have policies aimed at increasing the overall performance of all school children. This fits with research findings in mathematics about how working like mathematicians can engage students in the learning of mathematics and strengthen their understandings (e.g. Burton, 1999).

Commentators overwhelmingly draw the conclusion that the decline in student uptake of STEM is directly related to the inadequacies of school science, and its failure to excite student interest and engagement. For instance, Masters (2006) notes that the decline in numbers in post-compulsory science courses should be seen as directly related to the decline in interest in science from Year 4 to Year 8. He reported that many high school students see school science as uninteresting, unimportant and irrelevant to their lives, as a matter of rote learning facts, and as difficult to learn. The COSEPUP (2005) report focused primarily on the quality of teaching in STEM subjects and argued that the critical task is to improve school science and mathematics courses, and to attract more students into post-compulsory science and engineering. As well as increasing numbers, there is a need to nurture future ‘ideas workers’ to keep Australia on the cutting edge in research in Science, Engineering and Technology (Batterham & Miles, 2000).

Tytler (2007a, p. 7) identified four main elements in what is perceived to be a crisis in science education:

- evidence of students developing increasingly negative attitudes to science over the secondary school years
• decreasing participation in post-compulsory science subjects, especially the ‘enabling’ sciences of physics and chemistry, and higher mathematics.

• a shortage of science-qualified people in the skilled workforce

• a shortage of qualified science teachers.

These findings are also relevant to mathematics (Forgasz, 2006b; Siemon & Moroney, 2001), and point to a significant problem with student engagement with STEM subjects generally. Tytler (2007a) explored the dimensions of this crisis, arguing that the problem lay in a mismatch between the science curriculum, contemporary practice in science, and the lives and interests of students in post-industrial societies. Williams (2005) explored student engagement in mathematics in the middle years, and found that even in classes with recognised good teachers, there was little evidence of high-level intellectual and affective engagement with mathematics and where it did occur, it was upon the initiative of the student rather than as an explicit intention of the teacher. There is a need to further explore these phenomena with reference to STEM aspirations more generally and in particular to chart the key dimensions of students’ responses to school STEM subjects. This review will attempt to identify the factors that affect student responses to STEM participation at different points along the primary-secondary school continuum, with a view to informing policy aimed at supporting students’ greater engagement with and appreciation of science, technology and mathematics as subjects, and potential careers.

1.2 Methodology of the review

The review team brought considerable international experience and knowledge of student attitudes to and engagement with science and mathematics to bear on this research. The initial task involved pooling the team’s knowledge to generate a framework around which research then proceeded, and compiling a list of resources from previous research.

A series of keywords and search terms was generated. These terms were refined through team consultations as the search proceeded.

An online search strategy was developed which included searching library databases for journal articles, books and reports, the databases consulted include A+ Education, Australasian Digital Theses, Deakin University Library Catalogue, Dissertations & Theses (Proquest), Education Research Complete (EBSCO), Educational Resources Information Center (ERIC), Expanded Academic ASAP (Gale), Google Scholar, MERGA, Monash University Library Catalogue, University of Melbourne Library Catalogue, and Web of Science (ISI). These searches were supplemented by Google searches using the same search terms, and searches of government and industry group sites for reports and papers. Key government reports from Australia and the UK were mainly known to the team members, but were supplemented through consultation.
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People with knowledge of the field were approached to provide insights and to generate further searches. Researchers were consulted during international conferences attended by the group. These are detailed in the appendix.

An Endnote file, with appropriate search terms embedded, was compiled for the team’s use, and an abridged version of this database constitutes part of the electronic report.

The material was summarised by individual team members and shared amongst the team, and our argument and insights developed on the basis of shared analysis. The group communicated and consulted electronically, and through face to face and teleconferenced meetings. The draft documents were circulated to team members for further comment and refinement.

1.3 Overview of concerns about STEM supply and demand

It is widely believed that a flexible and highly literate STEM population raises the competitive advantage of Australia and leads to innovation and growth in productivity and wealth (Centre for Higher Education Management and Policy, 2004; DEST, 2006a). The resulting national policy priority to promote widespread participation in STEM has led to growing concern that Australia’s STEM-trained population is not sufficient to meet current and forecast demand. In the near future it is anticipated that Australia will face a large number of retirements in STEM-related fields, and outgoing professionals will need to be replaced with a new generation of STEM-literate workers. This anticipated outflow of STEM workers provokes widespread anxiety that current supply lines—domestic education and training, skilled migration, people returning to the workforce—will be overburdened, and that vacancies created due to retirements will remain unfilled.

Additionally, Australia faces growing international competition as other nations vie for STEM-literate workers, and growing demand as Australia’s population and economy grows and technological innovation creates new areas of growth. The U.S., Canada and the European Union compete with Australia for human capital (Allen Consulting Group, 2005). The “EU is saying that they need an additional 500, 000 to 700, 000 scientists by 2010. The corresponding figure for the US is 2.2 million” (Centre for Higher Education Management and Policy, 2004, p. 50). As competition heats up, the pool of talent that supplies Australia’s STEM skilled workforce may be reduced by offshore migration. Given this highly competitive and changing context, it is a major concern of government, community and industry stakeholders to foster, develop, and maintain Australia’s human capital in STEM fields (DEST, 2006a).

A number of factors impact upon the supply and demand of Australia’s STEM labour force, of particular importance with reference to Australia is the profile of the working population, global trends that shift the balance between inflow and outflow, new demand created by emerging industries, services and technological innovations, and Australia’s capacity and success in deepening the STEM skills of the existing workforce (DEST, 2006a). Characterising STEM participation and projecting
demand is thus a complex and difficult task and debate continues over both the current state of affairs and the likely trends. Arguments have in the past tended to focus on supply, with close attention to supply from education and migration, whereas painting an accurate picture of demand is hampered by the poor quality information. More research into the profile of STEM supply and demand, and more detailed modelling which could enable informed prediction and policy advice, is needed both in Australia and internationally.

A further complexity involves the nature of training needed for developing and maintaining an effective STEM workforce, and the multiple pathways between levels of participation in STEM occupations. It cannot be assumed that current education and training pathways are appropriate for the maintenance and development of Australia’s competitive edge. Increased global competition and increased pace of technical evolution is changing the nature of skills and training considered valuable. A premium price is put on employee flexibility, ongoing personal development and skill deepening, along with generic skills such as “self management, initiative and enterprise” (DEST, 2006a, p. 9; Engineering Working Group). Hence, in developing a robust technological capability, the question of the quality of training and education must be added to that of supply.

In order to characterise the issues, and model the balance between supply and demand, much research has adopted the model of a pipeline. The STEM pipeline plots an ideal trajectory that travels from early education to entry-level employment in STEM-related fields. As a cohort ages, it is evident that progressively fewer and fewer people participate in STEM-related study and employment, and the volume of throughput is dramatically reduced at transition, or ‘leakage’ points along the pipe. Each section of the pipeline builds upon the last. Failure to complete or fulfill requirements at one stage will invariably result in a narrowing of options in STEM at latter stages. The pipeline provides a useful way to visualise the relationship and interconnections between education and the Australian labour force. Across the primary-secondary transition numbers are not lost but students develop aspirations outside of STEM that influence their later choices. Thus in these years we can talk of a loss of aspiration related to STEM, and represent this as numbers both lost, or potentially lost, to STEM (Figure 1.1).
1.3.1 The Australian picture

The Department of Education, Science and Training’s 2005-2006 Audit of Science, Engineering and Technology Skills reports on current and projected demand in Australia, and identifies some trends that raise the level of concern. The audit identifies skill shortages in several areas, including some engineering professions, the finance sector, in SET trades, as well as a shortage of science professionals, particularly in geology, photonics and spatial information. It is notable that while these skill shortages exist, the proportion of people participating in STEM education and training in Australia “has remained static or declined, particularly in the enabling sciences (advanced and intermediate mathematics, chemistry and physics) over the decade to 2003” (DEST, 2006a).

Within the Australian science community there is concern at the declining number of students involved in STEM at the tertiary level. For example, a Royal Australian Chemical Institute report on the supply and demand for chemists notes, with concern, the decline in the number of students taking chemistry at university, and the resulting strain on chemistry departments (Royal Australian Chemistry Institute, 2005).
A number of submissions to the Victorian Parliamentary Inquiry into the promotion of mathematics and science education, by science industry bodies, provide insight into the level of concern. Engineers Australia reported that Australia produces fewer engineers per head of population than other OECD countries. Many submissions raised concerns about declining university enrolments in physics, chemistry, advanced mathematics, statistics, and engineering. Concerns of this nature were raised by Science Industry Australia, Engineers Australia, Minerals Council of Australia (Victorian Division), BioMelbourne Network, Australian Institute of Physics, Victorian Institute for Chemical Science and the Australian Council of Deans of Science.

Recent research has shown relative declines in developed countries in the proportions of students in STEM subjects at school, college and university (DEST, 2003; Ertl, 2005; Roberts, 2002). For example, (DEST, 2003) reported an overall decline in commencing enrolments in undergraduate courses in the physical and natural sciences between 1997 and 2002. A recent Victorian government inquiry into the promotion of mathematics and science education (Victorian Parliament Education and Training Committee, 2006) found that although there has been an increase in enrolments in senior school Biology, Chemistry and Further Mathematics since 2000, enrolments in the ‘enabling sciences’ (physics, chemistry and advanced mathematics) are at alarmingly low levels.

Between 1996 and 2006, employment in the professional and technical fields grew much faster in Australia than overall employment, at an average annual rate of 4.5%.1 Keeping pace with this growth has required an acceleration in training in STEM fields. The critical question is whether the inflow of trained STEM workers is adequate to maintain equilibrium, given the complexities with and constantly changing nature of demand. Figures from the OECD’s Education at a Glance (2007a) publication show that the number of science and engineering trained people in the 25 – 34 age range far outweighs those in the 55 – 64 age range in Australia.2 Since, broadly speaking, a ratio for these figures of one

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1 OECD (2007) Science, Technology and Industry Scoreboard 2007. “Professionals (ISCO group 2) include physical, mathematical and engineering science professionals (physicists, chemists, mathematicians, statisticians, computing professionals, architects, engineers), life science and health professionals (biologists, agronomists, doctors, dentist, veterinarians, pharmacists, nursing), teaching professionals, and other professionals (business, legal, information, social science, creative, religious, public service administrative). Technicians and associate professionals (ISCO group 3) includes: Physical and engineering science associate professionals, life science and health associate professionals, teaching associate professionals, other associate professionals (finance, sales, business services, trade brokers, administrative, government, police inspectors, social work, artistic entertainment and sport, religious),” p. 50.

2 However, the ABS (2007) undertook a similar generational comparison, finding that while Engineering & related technologies still represents one of the most widely studied fields of education among males in Australia, its popularity among males across generations has decreased, the ABS observing that “the proportion of men with their highest non-school qualification in this field increased with age – from 31% of men aged 25–34 years to 38% of men aged 55–64 years in 2006,” which the ABS surmises is attributable to lessening demand for some
would indicate that rate of replacement is in balance with rate of attrition from retirement, the figures reveal a reasonably healthy stock of scientists and engineers in Australia. It needs to be recognised, however, that this indicator is insufficient for a convincing analysis of the state of the Australian workforce, as it does not consider how or whether people are employed or whether they possess sufficient capacity to meet workforce demands, and does not put the ratio into the context of market and population changes.

Recent trends in the STEM teaching workforce are particularly worrisome. Half of Australian science teachers under 35 years of age have studied no physics at all (Harris, 2006; Harris, Jensz, & Baldwin, 2005). While there is presently some difficulty with teacher recruitment in the physical sciences and mathematics, this is expected to become more acute in secondary schools the next few years as the ageing profile of the STEM teacher workforce has led to forecasts of comparatively high replacement demand for STEM teachers. Additionally exacerbating the issue, the student population in secondary schools is also forecast to increase over the next few years.

1.3.2 STEM occupations and STEM capacity building

There is ongoing debate concerning the occupations that should be included in any description of engagement with STEM. The classification is performed in Australia using occupational coding, with two major coding systems being used; the ASCO and the ANZSCO codes. In thinking about the STEM pipeline, a narrow set of occupation codes tends to be used that includes engineering and physical science related professionals. There is a range of occupations in the health sciences, including medical practitioners, nurse educators, occupational therapists etc., which are clearly science based but not obviously allied to the immediate problem of Australia’s technological capability, and debate continues about whether they should be included in policy thinking on the STEM pipeline issue. Science and mathematics and technology teachers, who are critical to the supply side of the issue, and more broadly based educators in resource centres, and working in the media, tend to be discounted despite their obvious contribution to future STEM capacity. The analysis of supply and demand in these terms counts as ‘wastage,’ what might better be thought of as cross-fertilisation (See (Ackers, 2005a, 2005b; DEST, 2006a; European Commission, 2001). It seems clear, therefore, that while useful analysis can be pursued around the pipeline outputs related to engineering and science professionals in areas that may be in short supply, a broader characterization is also needed. The ongoing debate about what to include in and what to exclude from the STEM pipeline ends up masking the real issue at hand, namely how can education, workplace, and migration policies in Australia optimise the fit between supply and demand, and how can we ensure that education is flexible enough such that individual choice of pathways can be realized, without rendering people incapable of re-engaging with STEM?

engineering and related professions “(including Automotive engineering, and Electric and electronic engineering) over the last decade.”
Opening up pathways into STEM

One useful analysis of STEM occupational categories carried out by the UK Council of Science and Technology Institutes (Science Qualifications Task Force (UK), 1994) used questionnaires and workshop discussions to establish three different levels of knowledge of science, technology and/or mathematics needed in different occupations. They developed a framework consisting of levels of ‘criticality’:

1. MAIN occupations where the practice of science, technology and/or mathematics is the main activity of those employed (e.g. chemists, pharmacists, statisticians, medical radiographers, laboratory technicians. 0.6 million workers across the UK in 1993);

2. CRITICAL occupations where the main occupational function is not science, technology or mathematics but where the knowledge, understanding or practice of science, technology and/or mathematics is critical to occupational competence (e.g. computer systems managers, engineers of all kinds, nurses, medical practitioners, school science teachers. 1.7 million workers across the UK in 1993); and

3. ENHANCED occupations where the main occupational function is not science, technology or mathematics but where the knowledge, understanding or practice of science, technology and/or mathematics enhances occupational competence (e.g. farm, forestry or fishing managers, goldsmiths, textile operatives, hairdressers. 0.97 million workers across the UK in 1993).

The immediate purpose of the report was to argue for the development of a framework of occupational standards to support STEM planning. However, the report points out “that competence in these areas underpin almost every sector of our economy, is of major importance to every aspect of life, and that the existence of a workforce with the appropriate range of competences in these areas is vital to our future well being” (p. 1). The argument here is for a more layered and inclusive conception of what participation in STEM might mean for building a country’s well being and technological capacity.

Thus far in this review, the ‘problem’ of STEM participation has been couched in terms of workforce supply and demand in relation to STEM core employment fields, and training in the high school and university sector, mainly focusing on science, engineering and mathematics. However, a number of complexities in this equation have been introduced, relating to movement of graduates into and out of STEM fields, the value of human capital that lies outside core STEM fields (such as employment in STEM policy and management fields, and journalism in STEM areas), and the inclusion of employment trajectories that lie outside the academic pathway implied by a pipeline, which make apparent the need for a broad reconsideration of STEM capability. The pipeline casts the sole value of science and mathematics education as a pre-professional preparation for work. It fails to recognise the cultural value of science and mathematics as an intellectual activity in its own right and a discipline that may be of intrinsic interest to many young people.

Our research has found that the most salient factors affecting participation in STEM are not described adequately by the pipeline. It is difficult use the pipeline, for example, to characterise the possible...
levels of excitement, future-directedness and aspirational nature of attitudes toward STEM, which play a vital role in a person’s decision to pursue, or not, a STEM pathway.\footnote{Although numerous studies that use the pipeline model describe a subtle array of factors that influence student choice and levels of participation, our research has revealed other models that would be better adapted for such studies. See Adamuti-Trache and Andres, Eccles, Fouad, Hackett and Watt as examples of such studies.} It is difficult to modify the pipeline sufficiently to account for a number of circumstances that are crucial for an investigation of the value of STEM, in particular the people, structures and systems that support STEM capacity, identity issues relating to participation, choice and aspiration, the learnt capacity to be resilient in STEM, and the relative nature of the global STEM market. Given the evidently complex network of influences that impact upon people’s attitudes towards STEM, a model that is based on a head-count is imperfect for an in-depth analysis. Nevertheless, the pipeline metaphor will remain important, and used in this review, for reviewing literature on factors affecting participation in STEM related subjects in school and into higher education. Other metaphors will be used, however, to frame the issue more widely. Thus, the argument being advanced is that, while the pipeline metaphor provides a useful way of thinking about the supply of workers in particular and important STEM occupations which are likely to be in shortfall, the notion of capacity building, involving a richer and broader framework of STEM occupations, is needed to consider the impact of STEM on the technological, economic and social well being of a nation.

Capacity building recognizes the need to enhance the general public’s knowledge of STEM ideas and practices. Thomas (2000), for example, observes that mathematical skills underpin a huge variety of professions, ranging from science and technology to health to business and design, and the Australian Academy of Sciences (2006) identifies high-end mathematical skills as crucial for Australia’s success in a wide range of fields, including mining and resources, biotechnology, statistics and finance, environmental risk assessment and manufacturing and trade. Symington and Tytler (2004) argued that there were many ways in which individuals could be productively engaged in contributing to the STEM capability of a country. They cited community leaders with little or no formal training in science, yet who were actively involved in managing or supporting STEM industries and workers, as evidence of the need to take a broader view of the purposes of school science and the knowledge and dispositions that would enable engagement with science at different levels, spanning an individual’s lifetime. In a later study, based on focus group discussions with science professionals working in Australia’s research priority areas, Tytler and Symington (2006) highlighted the critical importance of having a scientifically informed and oriented public to support research and development in emerging technological areas, or public science policy areas. Communication of science by scientists and the media were argued to be critically important to the STEM enterprise, to inform policy frameworks, and enlist and maintain public support for innovation.

Building capacity in mathematics is also crucial, and related to facilitating in students personal or deep engagement with their subject-matter. Engaging students in mathematical problem solving situations that stimulate intellectual activity and build deep mathematical understandings are highly important,
and have been associated with encouraging in students personal characteristics that will enable them to continue to succeed in mathematics in the future. Williams (2007) has identified classroom activity that theoretically (Seligman, Reivich, Jaycox, & Gillham, 1995) should build such characteristics. In preparing for STEM careers, students need to develop a deep and connected understanding of mathematics that will enable them to be flexible in solving unfamiliar, non-routine problems (Batterham & Miles, 2000; Kilpatrick, 2002). This involves recognising the mathematics that is appropriate and being able to interpret mathematical results. These capabilities are those that are needed in developing 'ideas workers' for cutting edge STEM work (Batterham & Miles, 2000). They are the same capabilities needed in other STEM careers, and also by members of the community who need mathematical literacy in their daily working and personal lives.

Thus, capacity building in STEM needs to be seen not only through a lens of supply of technical workers, but also through a broader lens of public engagement with STEM. We shall see that this has important implications for how we think about student aspirations and decisions in schooling. Our research indicates that STEM needs to be reframed as something that serves and nourishes the community in general and young people in particular. As well as conceptualising people within one cohort as either maintaining a specific allegiance to STEM, or choosing to opt out at particular exit points, it is valuable to also conceive STEM more broadly in terms of multiple pathways where there is opportunity to refocus on STEM pathways after periods of non-participation.

### 1.3.3 Pathways into STEM

The pipeline model of participation in STEM assumes a linear progression of qualifications and subject participation, with each decision point influencing, often irrevocably, the nature of further participation along the pipeline. Each decision not to participate is a loss, or leakage. As we shall see, these decisions may involve aspirations and orientations that influence future paths by virtue of identity commitments rather than tangible choices, whereas others, such as decisions to opt out of mathematics or take lower level mathematics, materially influence future choices. Mathematics in particular has this pre-requisite character, and there is evidence that students are not always allowed to make their own decisions about which mathematics they take. The review will show that successful participation in middle school mathematics is the best predictor of future completion of STEM qualifications. For this track through academic subjects in secondary school, with its patterns of locked in prerequisites and performance dependent subject choice advice, the pipeline metaphor is useful and research built around it has yielded insight into factors affecting these choices and denying these opportunities.

However, changes in subject participation in middle and senior school are influenced by the wide variety of subjects students can choose between, and leakage from the academic STEM pipeline may not necessarily mean a loss of interest in STEM. Thus, for instance, the growth in VET subjects in schools and the multiple pathways into Technical and Further Education that are possible now in all Australian States, mean that students have the opportunity for serious participation in technical STEM
areas leading to certificate qualifications. This cohort of students were hitherto not part of the academic high school cohort of the 1950s through to the 1980s who chose STEM subjects in greater numbers, and it is often argued, with some justification, that the decreasing percentage of student choosing physical science and higher level mathematics is in part due to the huge increase in the population remaining at school to upper secondary level. However, opting out of physical science or higher level mathematics to seriously pursue technical VET subjects, rather than being thought of as leakage, might better be recognized as participation in an alternative pathway into STEM careers. Furthermore, it is possible to convert from these certificates and diplomas into degree courses, and part of the policy options available to increase STEM participation at the more academic level may be to recognize and encourage these pathways.

Within the STEM occupations there are also pathways that could be considered productive in maintaining a healthy and vigorous STEM community. The movement of STEM trained graduates into management and policy areas, or into science related areas outside their disciplinary background, is both common and potentially productive. Enlisting engineers into Diploma of Education courses to become teachers is not uncommon, and while their special expertise can be somewhat lost in the academic mathematics and science courses that currently predominate in Australian middle schools, we shall see that their backgrounds could be productively harnessed, given the right conditions, to introduce more authentic and engaging practice into school science and illuminate the usefulness of mathematics.

Hence, a further metaphor through which to analyse movement through schooling and work in STEM occupations is that of **pathways**, with the more nuanced and flexible view that this provides of the choices people make.
2 Supply and Demand

2.1 Current and anticipated needs for STEM workers

It is difficult to accurately forecast workforce demand, and the lack of available data in Australia stands testament to this difficulty (Richardson & Tan, 2005). Peter Andrews, Chief Scientist, Queensland, claims that Australia needs between 40,000 and 150,000 scientists by 2010 (Centre for Higher Education Management and Policy, 2004). The DEST (2006a) audit projects the demand for science professionals to increase by around 55,000 to 2012-13, and demand for engineering professionals to increase by over 46,640. Both these areas are underpinned by mathematical qualifications. One reason for the difficulty with projections, and thus their discrepancies, is that there is significant disagreement between stakeholders on what counts as skills shortage. Shah and Burke observe that it “is rarely possible to provide an unambiguous single measure of skills imbalance” (2005, p. 54) Highlighting this difficulty is the DEST (2006a) Audit of Science, Engineering & Technology Skills, which undertook to gather evidence across a suite of indicators on Australia’s capacity to supply an adequate number of skilled workers to meet market demand. The report found that while Monash labour demand projections predict that supply of STEM professionals will keep pace with demand in the next few years, barring the health professions, industry surveys indicate that there is already a shortfall in skill supply.

A number of market indicators point to current shortages in the engineering profession in Australia. Labour market data reflects high demand for engineers and employers report experiencing recruitment difficulties in a number of engineering occupations across all Australian states. Extended recruiting periods and rising wages are also in evidence. In 2006 DEWR identified, among others, shortages of Civil Engineers and Electrical Engineers in most states, and shortages of Chemical Engineers and Petroleum Engineers in Queensland and Western Australia (Figure 2.1).
Opening up pathways into STEM

Figure 2.1: Demand for professional engineering occupations by State/Territory, Australia, July 2006

<table>
<thead>
<tr>
<th>ANZSCO</th>
<th>Occupation</th>
<th>NSW</th>
<th>VIC</th>
<th>QLD</th>
<th>SA</th>
<th>WA</th>
<th>TAS</th>
<th>NT</th>
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<tr>
<td>23311</td>
<td>Chemical Engineer</td>
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<tr>
<td>23321</td>
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<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
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<tr>
<td>23331</td>
<td>Electrical Engineer</td>
<td>S*</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>23341</td>
<td>Electronics Engineer</td>
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<td></td>
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<tr>
<td>23351</td>
<td>Mechanical Engineer</td>
<td>S*</td>
<td>D*</td>
<td>S*</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>23361</td>
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<td>S</td>
<td>S</td>
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<tr>
<td>23362</td>
<td>Petroleum Engineer</td>
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<td></td>
<td>S</td>
<td>S</td>
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<td></td>
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<tr>
<td>233513</td>
<td>Production/Plant</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Engineer</td>
<td>S*</td>
<td></td>
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</tbody>
</table>

Source: DEWR (2007) *Australian Labour Market Update*

In the table, S stands for State-wide shortage, D for recruitment difficulties, an asterisk (*) identifies qualifying comments and blank squares represent that no information is available.

The market story for other STEM fields is less compelling, though not without interest. The Australian Department of Education, Employment and Workplace Relations (DEEWR) publishes regular updates on trends in the Australian labour market in which employment prospects are forecast some years hence for selected occupations. Many STEM occupations are forecast to retain good employment prospects to 2012, including Computing Professionals, Chemical Engineers, Information Technology Managers, Mining and Materials Engineers, Pharmacists, and Electricians, among others. Yet because skill shortages may exist in a sector in conjunction with relatively high unemployment, relative employment rates are not a sufficient indicator. Figure 2.2 below shows that skilled vacancies for science professionals were 26.5% higher in April 2008 than the previous year, and vacancies for Medical/Science Technical Officers over the same period increased by 87.6%.
Another factor in the supply equation is whether or not trained STEM professionals are working in relevant STEM fields. Under-utilisation of SET skills within the labour force, as measured by the numbers of persons who are employed in occupations unrelated to their SET degree, and the number of SET-skilled persons not in the labour market, led DEST to estimate a possible 35% shortfall of science professionals to 2012–13. Over the same period DEST estimates that demand for engineering professionals may already exceed supply by approximately 2,000 persons, and observes a significant and continuing gap between the supply and demand of engineering tradespersons (DEST, 2006a).

There continues to be some debate over what is being measured, and how, in studies of STEM participation, as well as concern regarding the completeness of data collected on levels of STEM demand, and the accuracy of projections on future demand (J. Osborne et al., 1997). As a result, some doubt is cast over the claims of policy makers regarding the urgency of the labour force shortage in STEM related areas. One notable example of this line of critique is Michael Teitelbaum (2003, 2007), who questions claims made by some policy makers and researchers that the US faces acute shortages of STEM professionals, and argues that relatively high unemployment rates in science and engineering fields in the US belie the shortage thesis. He observes that pronouncements of shortfalls in STEM related fields tend to be a product of poor methodology and limited data. “Few, if any, of the market

<table>
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<th>Apr-2008</th>
<th>Index Apr-2008</th>
<th>% change</th>
<th>No. of Vacancies Apr-2008</th>
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<td></td>
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<td>Monthly</td>
<td>Annual</td>
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<td>PROFESSIONALS</td>
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<td>Science</td>
<td>123.4</td>
<td>5.5</td>
<td>26.5</td>
<td>85</td>
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<td>Building and Engineering</td>
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<td>-4.9</td>
<td>-16.4</td>
<td>235</td>
</tr>
<tr>
<td>Accountants and Auditors</td>
<td>70.2</td>
<td>-6.6</td>
<td>-38.4</td>
<td>130</td>
</tr>
<tr>
<td>Health</td>
<td>102.4</td>
<td>1.0</td>
<td>0.6</td>
<td>664</td>
</tr>
<tr>
<td>ASSOCIATE PROFESSIONALS</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Medical/Science Technical Officers</td>
<td>151.9</td>
<td>1.7</td>
<td>87.6</td>
<td>33</td>
</tr>
<tr>
<td>Building/Engineering Associates</td>
<td>69.8</td>
<td>-5.4</td>
<td>-26.3</td>
<td>121</td>
</tr>
<tr>
<td>TRADES</td>
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<td>-0.5</td>
<td>1.0</td>
<td>2519</td>
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<tr>
<td>Metal</td>
<td>109.9</td>
<td>1.6</td>
<td>18.2</td>
<td>543</td>
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<tr>
<td>Automotive</td>
<td>95.5</td>
<td>0.1</td>
<td>-5.9</td>
<td>297</td>
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<tr>
<td>Electrical and Electronics</td>
<td>104.6</td>
<td>1.2</td>
<td>8.2</td>
<td>322</td>
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<tr>
<td>Construction</td>
<td>102.1</td>
<td>-1.6</td>
<td>6.2</td>
<td>668</td>
</tr>
</tbody>
</table>

indicators signalling shortages exist” (Teitelbaum, 2003). In “most areas of science and engineering at present, the available data show sufficient numbers or even surpluses of highly qualified candidates with extensive post-graduate education” (Teitelbaum, 2003). Richardson and Tan (2005), likewise highlight the difficulties with forecasting, and warn that the inaccuracy of forecasting render projection models only marginally useful for workforce planning. Likewise, Leigh (2008) warns of the problems associated with subsidising young people today to enter fields of education based on projections of shortages tomorrow, where a better strategy might be to invest in workforce capacity by investing more generally in human capital. These doubts raise a number of questions about how to best measure market imbalance.

### 2.1.1 Demand

The DEST audit describes two components of demand that each contribute significantly to estimations of balance or imbalance between workforce skills and industry requirements. The first component is ‘new’ demand, which arises from economic growth, and the development of new technologies that lead to the creation of new jobs. The second component is ‘replacement’ demand, which arises from turnover, retirements, and worker mobility. Broadly speaking, the workforce will be in balance when the ratio of supply to demand is 1:1, yet, as Shah and Burke observe, the “desirable level of qualified people in an occupation is not static” (2006, p. 2). In this context, replacement is complicated by a number of mediating factors, including the changing nature of employment, with the number of part-time jobs likely to increase in the future, the rate of economic and employment growth, and levels of participation in the labour force.

‘New’ demand can be significantly harder to forecast than ‘replacement demand’ because the feedback provided by market indicators is based on past data that may no longer be relevant. Additionally, because technological development leads to highly variable market outcomes, it is often difficult to forecast resulting demand. For instance, who, twenty years ago, would have predicted the number of people employed in web design? Some of the complexities are reflected in the box below.
Demand in STEM occupations is affected by overall economic conditions. Employment growth in Australia is “forecast to increase by 1.1 per cent per year, increasing from 10.04 million in 2006 to 11.23 million in 2016. This is significantly lower than the 2.1 per cent annual growth rate for the previous decade” (Shah & Burke, 2006, p. 27).

The ageing profile of the Australian workforce, the rate at which people change occupations, and the increasing number of part-time jobs will each influence the level of demand for skills and qualifications. Retiring workers create replacement demand, part-time jobs effectively require more training and qualifications than do full-time jobs, and high worker turnover will result in additional training needs. “DEWR estimates that in the five years from November 2005, the impact of population ageing will be equivalent to a shortfall of 195,000 workers” (DEST, 2005a).

Average ‘replacement demand’ for all Australian occupations between 2011 – 12 is expected to be 3.2%, while replacement demand over the same period for SET occupations is expected to range from 2% to 12% (DEST, 2006a). While negative growth (-0.8%) is forecast for Mathematicians, Statisticians, and Actuaries, replacement demand is expected to exceed the national average at 5.9%. In the SET trades, high levels of replacement demand are forecast for Forging tradespersons (9.2%), General fabrication and engineering trades (8.8%), and Electronic instrument trades (9.6%).

In the Natural and physical sciences, employment growth between 2004–5 to 2012–13 is expected to be around 33.3%, while for Engineering over the same period, it is expected to be 13.5%, and around 32.5% in Mathematical Sciences. The growth in Agriculture is expected to slow down to 36.2%, compared with 56.8% between 1996–7 and 2004–5 (DEST, 2006a, p. 5).

The research on demand in STEM areas shows a consistent risk that supply will not keep pace in particular areas and professions such as engineering, earth sciences, chemistry, and high-level mathematics and statistics (DEST, 2006a). The needs of industry change rapidly, there is an evident shift in demand for highly qualified mathematicians, with far more taking up positions involving problem solving where traditional positions were generally more focused around actuarial work and calculation. While there are difficulties with accurate projection, and workforce planning is restricted to a large extent, it is fairly clear that demand for high levels of mathematical and technical competence will grow in the future, and young people will find it significantly harder to thrive in a world without gaining these necessary skills. As Thomas (2000) observes:

As societies have become more technologically advanced, the importance of mathematical knowledge has increased and, if individuals are denied access to this knowledge, they are denied access to part of their culture as well as many other opportunities within that society (p. 3).
What is harder to predict is the specific level of demand, and there is a danger of overstating the crisis in STEM skills shortages. An example of such overstatement is detailed by Shah and Burke, who describe two reports on skill shortages in IT, including projections of 180,000 additional workers for 1999 – 2004, written at the height of the dot com bubble. The projections were based on employer surveys, and if the projections were accurate “it seemed that severe skills shortages were unavoidable unless other policies were quickly implemented” (2005, p. 62) Three more reports followed in 2001, all projecting skills shortages, and all based upon figures produced in the previous reports. A further study came out in 2002, still reporting shortage. The dot com bubble burst in early 2003, resulting in a softening demand and a 41% reduction in job advertisements, high unemployment, and a drop in average salary of 8% for ICT personnel. In September 2003, Chelsey Martin in an article entitled ‘Fear of skills shortage as students shun IT,’ published in the Australian Financial Review, “reported a drop of 25% in the enrolments for IT programs in universities.”

2.1.2 Globalisation, supply and demand

Globalisation raises a number of specific issues related to STEM supply and demand.

- Increased workforce mobility dramatically changes the context in which STEM is considered. “Migration to and between OECD countries has... increased markedly as OECD countries seek to address skill gaps. Intra-company transfers are also on the rise, as is the incidence of cross-border workers” (Centre for Higher Education Management and Policy, 2004; DEST, 2006b).

- The extent to which globalisation will impact upon industry within Australia depends upon level of vulnerability, level of exposure, and insulation from global competition, and will vary markedly across industries (Shah & Burke, 2006).

- Increased specialisation in products and services is a likely trend, as is uneven concentration of knowledge/skills in areas of natural or created advantage (DEST, 2006a; European Commission, 2004).


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4 Similarly, the Dainton Report in 1968 in England also forecast serious problems which did not emerge.
2.1.3 Supply

Australia relies upon both a skilled migration program, and domestic development, education and training to feed the pool of STEM-literate workers. In order to continue to attract skilled workers from overseas, and retain its domestically educated population, Australia must remain globally competitive and continue to be a relatively attractive destination (Allen Consulting Group, 2005). Migration laws, comparative remuneration, and availability of funding and facilities together have a large degree of influence on global STEM mobility (Allen Consulting Group, 2005). Government investment in research and development influences market share in key industries and Australia’s capacity to attract talented people from overseas. Australia’s spending on research and development is less than many OECD counties (Figure 2.3).

Figure 2.3: R&D expenditure as a per cent of GDP, 2002 -2003, OECD counties

Australia continues to be an attractive destination for overseas workers, and has a good track record in marketing itself as such. The net inflow of skilled workers to Australia from international destinations over the five years to 2001 in numerous STEM occupations when expressed as a percentage of total stock, represents 13% of Chemists, 14% of Geologists and Geophysicists, 7% of Mathematicians, Statisticians and Actuaries, 15% of Life Scientists, and 19% of Engineers. Having said this, there is some concern that Australia is losing trained and highly skilled candidates to overseas markets in some specialty areas, including mathematics (Centre for Higher Education Management and Policy, 2004; Thomas, 2000).

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\(^5\) See the Appendix for a complete list of Migration Occupations in Demand (MODL).
Deepening the skills of the existing labour force also contributes to the supply of Australia’s STEM workforce. On average between 2001 – 2005 qualifications of persons in the Australian labour force have increased in Science (3.4%), IT (9.9%), and Engineering (0.8%) (Shah & Burke, 2006). The question addressed in the following sections concerns participation of students in STEM courses. The analysis shows the enrolment and graduation patterns in various areas of STEM in recent years.

2.2 Education and STEM

2.2.1 Graduate employment in STEM occupations

Recent data from the Australian Bureau of Statistics (2007) indicate that people who hold Natural and physical sciences degrees—which includes degrees in mathematics and life sciences—have very good employment prospects,

In 2006, people who held their highest non-school qualifications in the fields of Health, Education and Natural and physical sciences had the lowest rates of unemployment (1.5%, 1.9%, and 1.9% respectively). This indicates a high demand for these skills within the workforce.

Employment prospects for recent engineering graduates are also strong, with DEST (2006a) observing that “employment and salary outcomes for university bachelor engineering graduates were generally stronger than those for science graduates and most other disciplines.” Figure 2.4 shows that employment prospects for STEM graduates are overall better than the general population. This data, however, does not detail the specific roles that graduates are employed in or whether they are employed in their field of specialisation.
In the ten-year period from 1990 to 2000, McInnis, Hartley and Anderson (2000) studied student outcomes for science degree holders. This study found that science degrees for most graduates were effective to gain entry to employment and that the surveyed science graduates generally reported high levels of job satisfaction. Students who reported completing a ‘generalist’ Science degree experienced higher levels of under-employment than did students who reported that their degree was more specialised. While this is the case, McInnis et al.’s study also indicates that employers require a broad range of skills from science graduates, and value personal skills very highly — such as ability to communicate with others, ability to work in a team, ability to make decisions, and problem solving skills — in addition to technical skills acquired in the course of formal STEM studies.

Data from a questionnaire survey of science graduates exploring the adequacy of the science degree for future employment needs (M. Anderson, McInnis, & Hartley, 2003) indicated that about half of their sample of employed graduates were in positions outside their discipline base. This figure is supported by other studies:

Science graduates are nearly as likely to pursue non-scientific roles as research and industrial roles in the scientific industries. Indeed, surveys have shown that around 40% of science graduates use the skills and processes they learnt whilst studying science (rather than their knowledge of science) to undertake roles in a wide range of areas. Graduates pursue roles associated with science (science editors, journalists, patent attorneys, commercialisation agents, government policy analysts) or use their transferable skills (particularly mathematics) in business (for example management consulting, business analysis, stock broking, insurance, banking, risk assessment, analysis and utilities management). (Graduate Careers Australia, 2007, p. 4)

In a study of science graduates working ‘out of field,’ Rodrigues et al. (2007) found that the graduates were often working in related fields, and felt they used the analytical and methodological skills they
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had learnt during their degrees, in their current jobs. They were critical, however, of their training in the more generic communication and ‘people’ skills that they found central in their current employment. Symington and Tytler (2004), in a study of community leaders’ involvement in science, found that their non-science trained informants were often involved in STEM enterprises, in some cases managing STEM-related industries and workplaces, being involved in STEM related policy work, or in sustainability projects. These studies point to the need for more diverse thinking about what constitutes involvement in STEM, to support Australia’s advancement as a technologically capable nation.

There is some concern that the SET field of education (FOE) is not attracting the highest quality candidates to tertiary courses. The highest calibre students — as judged by Tertiary Entrance Rank — are choosing health related fields of education such as Dental Studies, Medical Studies, and Veterinary Studies, over Education, Natural & Physical Sciences, and Agriculture, Environmental & Related Studies. Strong competition prevails in the health FOE and “Medical Studies and Veterinary Studies are accepting less than 25% of eligible applicants” (DEST, 2005a). The DEST audit observes that “university teachers and academics expressed concern that the quality of SET education in schools was limiting their capacity to graduate students suitably qualified to meet the high expectations of industry” (DEST, 2006a). Similarly, the Australian Council of Engineering Deans (R. King, 2008), observe that a high level of concern exists amongst educators and industry regarding the entry standard of tertiary Engineering courses, and describe the ‘tyranny of the tertiary entrance rank,’ which King (2008) argues tends to dominate student choices of Higher Education programs, and restrict the capacity of some programs, for example Engineering & Related Technologies (ERT) and Education, to attract the most worthy and interested students.

2.2.2 Trends in Tertiary STEM participation


Primary enrolments in Natural and Physical Sciences courses expanded by nearly 4,300 enrolments, or 7.1 per cent, compared with a system-wide average of 6.8 percent. The number of Science course enrolments as a proportion of all enrolments remained almost unchanged at 6.7 to 6.8 per cent (Dobson, 2007, p. 16).

When enrolment figures in the Natural & Physical Sciences are disaggregated into specific course-loadings, downward trends are evident in levels of participation in the Physical, Chemical, and Mathematical sciences. Over the same period, an upward trend is evident in Biological and Behavioural sciences (Dobson, 2007). For example, between 1989 and 2005, enrolments in the Mathematical Sciences decreased by 33.7% (down to 4,988), in the Physical Sciences by 19.4% (down to 2,911), and in Chemical Sciences by 5.3% (down to 5,617). In the same period, Biological Sciences
increased by 74.9% (up to 18,624) (Dobson, 2007, p. 71). Given Mathematics’ pre- eminent role in empowering research, development and innovation in all other STEM disciplines, the steady decline in Mathematics infrastructure is of great concern (Australian Academy of Sciences, 2006; Thomas, 2000). In 2003 only 0.4% of Australian university students graduated in mathematics and statistics compared with an OECD average of 1% (OECD, 2005a).

Women represent the majority of Australian university enrolments (54%) but less than a third of tertiary STEM enrolments. Females are under-represented in tertiary engineering (16%), computing (24%), Mathematics (39%), Earth Sciences (42%) and Physics (27%), and over-represented in Biological sciences (64%), while in Chemistry the proportion of female students is representative (54%) (Dobson, 2007). 26.1% of students enrolled in Mathematical Science in 2005 were international students, which is rather higher than the proportion of international students studying other science disciplines, “around 12 to 14 per cent in the Biological, Chemical and Physical Sciences” (Dobson, 2007, p. 40).

Figures from the OECD scoreboard (2007a) (Figure 2.5) show that the proportion of science and engineering degrees out of all new degrees in Australia has increased slightly since 1998, and in 2004 was between the OECD average and the EU19 average. The proportion science and engineering degrees, however, is much lower than many of Australia’s competitor countries.
Where overall trends in student numbers have increased slowly, or at worst decreased, there is evidence that enrolments fluctuate from year to year, and that they are amenable to intervention. The Higher Education statistics for the first half of 2007 indicate that enrolments increased from 2006 in ERT (11.1%), and Natural & Physical Sciences (3.6%). Whereas, over the same period, the number of commencing students declined in IT (-3.9%), representing a slower decrease than in previous years (DEEWR, 2007).

The substantial increase in the number of commencements in the field of Engineering and Related Technologies is a change from previous years—between 2005 and 2006 there was a small increase of 1.4% in the number of commencements while between 2003 and 2005 the numbers declined each year. The increase in the first half of 2007 is due partly to an extra 510 Commonwealth supported places offered in 2007. An extra 560 places will be offered in 2008 (DEEWR, 2007).

As such, it is evident that student enrolments will change relatively quickly in response to perceived employment prospects, scholarships and other programs.

Based on figures from 1992 and 1993 entry cohorts, completion rates for university undergraduate courses in Science and Engineering are relatively low, approximately 58% for Science, and 59% for Engineering, compared with 90% for Veterinary Science, and a median completion rate for all fields of study of 65%. King (2008, p. 39) corroborates these estimates, finding that “on average, male Australian engineering students have about 52% likelihood of successful graduation from a bachelor level engineering program, and females about 60.”

Upward trends are evident in postgraduate studies in STEM fields, for example in ERT, “PhD completions increased by 361.7% between 1989 and 2003” (DEST, 2005a, p. 89). Likewise, “PhD completions in Natural & Physical Sciences increased 427.7% between 1989 and 2003,” and now account for almost a quarter of all PhD completions (DEST, 2005a, pp. 89-90). However, within this, the Australian Academy of Science (2006) observes that total higher degree completions (MSc and PhD combined) in mathematics and statistics have stalled. As a result of the large increases in PhD completions, and the lesser increases in undergraduate enrolments, “the ratio between the number of people with undergraduate qualifications and higher degree qualifications is decreasing because a greater share of people have higher degrees” (DEST, 2005a, p. 89).

### 2.2.3 Secondary mathematics

Although the overall level of participation in mathematics courses in senior secondary school appears relatively healthy, once enrolment figures are disaggregated, there is evidence of a shift in Australia away from participation in Advanced and Intermediate mathematics courses towards Elementary mathematics courses (Barrington, 2006; Committee for the Review of Teaching and Teacher Education, 2003c; Forgasz, 2006a, 2006b; Thomas, 2000). This is of particular concern given that intermediate level mathematics and above is the critical gateway to the majority of tertiary STEM degrees, a finding reinforced by the Tai et al. (Tai, Qi Liu, Maltese, & Fan, 2006) research, which shows that the chance of doing a physical science degree increases exponentially the higher the maths score. Barrington (2006) identifies a -2.4% change in enrolments in Advanced mathematics between 1995 and 2004, and in the same period a -4.6% change in Intermediate mathematics enrolments, and a +9% change in Elementary mathematics enrolments. Over the five year period from 2000-2004, Forgasz (2006a, p. 215) identifies an overall decrease in enrolment in Year 12 Intermediate mathematics courses from 68,146 in 2000 to 64,596 in 2004. When expressed as a percentage of the

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6 Elementary mathematics courses are particularly difficult to classify, given that over 70 courses fall into this category Australia-wide (See Barrington, 2006; McPhan, Morony, Pegg, Cooksey, & Lynch, 2008).
Year 12 cohort, there is a small, steady decrease in the proportion of students participating in Year 12 Intermediate mathematics, from 36.7% to 33.4%.

Figure 2.6: Trends in Australian Year 12 mathematics enrolments, 1995 - 2004

The ratio of male to female student participation favours males in every Australian state except the ACT, and declines in the proportion of participating students can generally be explained by large decreases in female participation (Forgasz, 2006a). The proportion of female students participating in Intermediate mathematics is declining at a greater rate than the proportion of male students, and this trend leads Forgasz (2006a, p. 220) to observe that young women “are continuing to limit their career options by not pursuing subjects at the Intermediate level at Year 12.” This is a particularly concerning trend. While there was no significant decline in the overall performance of Australian students in mathematical literacy in PISA between 2003 and 2006, female student performance in mathematical literacy declined significantly, and Thomson and De Bortoli (2008a, p. 11) observe that contrary to

7 Forgasz notes that the wide divergence of proportions of Year 12 students participating in Intermediate level mathematics in each State is particularly interesting, given that Tertiary institutions overlook the massive variation in subject content and philosophy across Australia. Intermediate level mathematics courses in Australia are the most likely prerequisite for science/math-related tertiary degrees.
findings in PISA 2003, which indicated no gender difference in mathematical literacy, “Australian males significantly outscored females in mathematical literacy in PISA 2006, by 14 score points.” As mathematical literacy reflects the capacity to draw upon mathematics in new contexts to interpret data and solve problems rather than just reproduce taught procedures, this decline in performance for female secondary students is likely to have repercussions for their later participation in STEM pathways.

### 2.2.4 Secondary science

There has been over the past two decades a concern about the decline in enrolments of students taking science subjects in the final two years of secondary school both in Australia (Australian Council of Deans of Science, 2003, 2007) and internationally (American Association of State Colleges and Universities, 2005; Barmby, Kind, & Jones, 2007; Daly, Coe, & Defty, 2003). Steady declines in relative numbers are evident in Biology, Physics and Chemistry, while an increase in enrolments in the relatively new Psychology is evident, from around 5% in 1992 to just under 8% in 2002, as shown in Figure 2.7.

When expressed as a percentage of the Year 12 cohort, participation rates in Chemistry declined from a peak of 33% in 1980 to 17% in 2002, while in the same period, participation rates declined in Physics from 29% to 16%. Biology has also declined from a peak in 1977 of 58% to 25% in 2002 (Committee for the Review of Teaching and Teacher Education, 2003b). The proportion of students taking two or more science subjects at Year 12 has also declined steadily; for example the proportion taking Chemistry and Physics has declined from 15% in 1990 to 10% in 2001. This decline has further repercussions at tertiary level, given the observation of Dobson and Calderon (1999, p. 19) that the “more science subjects studied as part of VCE, the more likely a student was to enrol in a university science course.” Declines in absolute numbers have not been as dramatic as there has been a steady increase in retention to Year 12 in all states, although this has dropped off in 1997 in Western Australia and Queensland due to demand for labour (Australian Bureau of Statistics, 2008a). By expressing participation as a share of the full cohort of students, including those no longer in school, it can be shown that between 1981 and 1992 overall school retention rates increased substantially, as did share of participation in Biology from 18% to 30%, Chemistry from 11% to 18%, and Physics from 10% to 17%. But, between 1992 and 2002 declines are evident in Biology from 30% to 19%, in Chemistry from 18% to 13%, and in Physics from 17% to 12% (Committee for the Review of Teaching and Teacher Education, 2003b).
Figure 2.7: Trends in Year 12 participation rates in science subjects in Australian schools.

Although overall male and female enrolments in science are roughly equal, gender has been at the forefront of research with consistent evidence of differences in participation in favour of males in physical science (Burkam, Lee, & Smerdon, 1997) and within the physical sciences between Chemistry and Physics (Smyth & Hannan, 2003). It is clear that student interest in science is formed by experience and achievement in previous years of compulsory schooling, which only becomes a point of choice at upper secondary level where students can opt out of science; but it is less clear how students’ perception of the future — the perceived usefulness of subjects and their vocational plans — interacts with prior experience and individual psychology when students are making choices of upper secondary subjects (Ainley, 1993).

2.2.5 Secondary technology

Technology is a much more difficult area to count due to the variety of subjects offered. Technology includes IT related subjects such as information systems, software design and development, information processing and management, and technical studies, including materials and technology, design and technology, technology studies, textiles and design, home economics, agriculture, and development and graphics (See Committee for the Review of Teaching and Teacher Education, 2003b). In each of these subject areas, relative enrolments have increased overall between 1991 and 2002, with a small downturn in 2002. “Over the period from 1991 to 2002 enrolments in technical subjects more than doubled (increased by 16,396) and enrolments in information technology more than trebled (increased by 30,974)” (Committee for the Review of Teaching and Teacher Education, 2003b, p. 17).
2.2.6 VET pathways

Research undertaken by the Centre for the Economics of Education and Training found that a significant proportion of the qualifications held by people in the labour force in 2005 were at a VET level, including 15.3% in Science, 48.2% in IT, and 83.5% in Engineering. Of all enrolments in Vocational Education and Training (VET) courses in 2006, 17% were in Engineering & Related Technologies (ERT), while the ERT field of study accounted for 36% of people whose highest non-school qualification was Certificate I - IV (Australian Bureau of Statistics, 2006, 2008b). As such, it is evident that numerous pathways into STEM are available through VET (Blake, 2006). VET provides a valuable alternative for many secondary school students and early school leavers to attain post-school qualifications and re-engage in education, including in STEM fields such as Engineering, and in STEM trades, such as Electrical trades, selected Automotive trades, Draftspersons and Technicians, Metal Casting, Forging & Finishing trades, among others. At “current levels of supply, a shortfall in requirements of 240,000 people with VET qualifications can be expected in the ten years to 2016” (Shah & Burke, 2006, p. 44). In order to meet these requirements, completions from the VET sector will need to increase by 1.9% per year, while higher education completions will need to remain constant over the next ten years (Shah & Burke, 2006, p. 44). In 2002 of the 1.4 million award course enrolments, approximately one third were in science and technology courses, see Figure 2.8 (Committee for the Review of Teaching and Teacher Education, 2003c). While males tend to dominate enrollments in VET in Architecture & building (92%), and Engineering & related technologies (90%), females dominate enrolments in Natural & physical sciences (59%), and Education (58%) (Australian Bureau of Statistics, 2008b).
Figure 2.8: Course enrolments in science and technology in VET as percentage of all course enrolments, by field of study, 1996–2001.

Between 1996 and 2003 the proportion of students participating in Vocational Education and Training in Schools (VETiS) rose from 16% to 44% (Dalley-Trim, Alloway, Patterson, & Walker, 2007). Similarly showing strong enrolment trends, the Victorian Certificate of Applied Learning (VCAL) has been offered in Victoria since 2002, and in “2005, more than 10,000 students ... were enrolled in VCAL courses” (Walstab & Lamb, 2007, p. 47). While these enrolment patterns are promising, there is little evidence that VETiS offers a direct and significant pathway into STEM-related fields. The National Centre for Vocational Education Research (NCVER) undertook a study of VET in Schools in 2005. In the report, VETiS enrollments are disaggregated by industry categories, revealing a significant minority of student enrollments in the Tourism & Hospitality (21%), Business & Clerical (25%), and Sales & Personal services (10%) subject areas. Far fewer numbers are enrolled in STEM-related fields, for example, Engineering & Mining (4%), Automotive (3%), Computing (3%), and Science, Technical & Other areas (1%).

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8 Enrolments in lower level certificates (e.g. Certificate II) in IT are counted here in Business & clerical industry, inflating the numbers somewhat. These percentage estimates are approximate.
VETiS programs have tended to attract a very stable student population, most notably low achieving students (36%) with English speaking backgrounds, low SES, and those whose parents are not tertiary educated. Yet, there are many exceptions, and a significant proportion (13% in 2002) of high achieving students also participate in VETiS programs (Dalley-Trim et al., 2007). This stability is in part attributable to the implicit understanding held by some careers teachers, parents, and students that VETiS programs are ill-suited to high-achieving students, and the tendency for some parents and teachers to pay lip service to the programs, while continuing to regard VETiS as a “softer option and of low status” (Dalley-Trim et al., 2007, p. 29).

VETiS provides reasonably stable and positive outcomes for students, and young people can and do move between VET and higher education (Fullarton, 2001; Walstab & Lamb, 2007). The 2007 On Track longitudinal study of Victorian school-leavers shows that there is a reasonably high transfer rate (around one-quarter) from VET to University, and that “VET at all levels can be part of a pathway from school to university study” (Walstab & Lamb, 2007, p. 21). As such, VETiS continues to be a promising pathway into education and work for a large number of young people, and perhaps a number of measures can be taken to raise the status of VETiS, and to provide career guidance with a stronger commitment to expanding individual horizons (See Blake, 2007; Maxwell, Cooper, & Biggs, 2000).³

### 2.3 Teacher quality and teacher supply issues

While in the past the supply of Australian teachers has, broadly speaking, been in balance with demand, teacher workforce planning data indicates that there are critical shortages in the current teaching workforce and that this situation is likely to get worse in the near future. Some rural schools are experiencing acute difficulty meeting their staffing requirements, as are metropolitan schools with poor reputations, and schools in outer-metropolitan growth corridors (McKenzie, Kos, Walker, & Hong, 2008; Queensland Department of Education Training and the Arts, 2007; Senate Standing Committee on Employment Workplace Relations and Education, 2007; Teacher Supply and Demand Reference Group, 2006). The ageing profile of the Australian teaching workforce raises concerns about the capacity of Australia to meet demand in the future. The average age of Secondary School teachers has risen to about 44 years (McKenzie et al., 2008). Teacher attrition rates are expected to rise as many teachers retire, potentially exacerbating existing difficulties with recruitment.

Although teacher skill shortages are not restricted to the STEM fields, shortages are pronounced in some STEM areas (for example, Math, Physics, Chemistry, IT) (Committee for the Review of Teaching and Teacher Education, 2003c). Strategies adopted in schools to cope with skill shortages

³ The OECD (2004, p. 19) observes that to some extent in Australia “the growth of vocational courses within schools has ... been at the expense of career education programmes, not least because career guidance staff have often been deployed to play significant roles in setting them up and supporting them.”
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range from getting teachers to instruct out-of-field, concentrating best-trained STEM teachers at upper secondary, increasing class size, and decreasing subject-range (McKenzie et al., 2008; OECD, 2005b).

As indicated in Figure 2.9 the evident trend in enrolments is notable in STEM fields of education, where between 1992 and 2000, the share of enrolments in the Physical sciences out of all Bachelor of Education commencements diminished from 18.3% to 6.1%. Over the same period, the share of enrolments for the Chemical sciences also diminished from 8.4% to 4.9% (MCEETYA, 2004). Numbers of students with STEM degrees studying Post Graduate Teacher Education courses have also fallen over the same period.

Only around one in twenty-five of those who graduate in the general life sciences or mathematics, and one in fifty of those who graduate in the physical sciences, undertake teacher education in the year after graduation (Committee for the Review of Teaching and Teacher Education, 2003a, p. 19).

*Figure 2.9: Proportion of students undertaking STEM subjects in Education degrees, 1991-2000*

The decline in the number of teacher education students undertaking mathematics is particularly concerning given that the importance of mathematics in underpinning all areas of STEM. At tertiary level, there has been a decline in academic staff in mathematics departments in Australia, with the number of permanent staff in mathematics departments in the Group of 8 universities declining by a third (Australian Academy of Sciences, 2006; Thomas, 2000) although this decline has been somewhat ameliorated by an increase in sessional staff. Engineering departments have also experienced changes in their teaching workforce, with high growth in research-only staff and declines in the number of support staff (King, 2008).

Despite this critical need, the low status of teaching, as well as perceptions of poor salaries, and the lack of promotional pathways, have led to lessening interest among young people in pursuing careers in
teaching. Average ENTER scores for tertiary teaching courses have lowered (Alloway, Dalley, Patterson, Walker, & Lenoy, 2004; Teacher Supply and Demand Reference Group, 2006). Although ENTER scores are not an adequate measure of teaching quality, and a large portion of training teachers undertake postgraduate courses which do not stipulate ENTER requirements, the trend does indicate a poverty of competition in Australia’s tertiary selection process, and stands testament to the failure of teaching to attract candidates of the highest calibre (Barber & Mourshed, 2007; Leigh & Ryan, 2006).

It is critical to the quality of education systems internationally to recruit well-qualified and able teachers (Rivkin, Hanushek, & Kain, 2005; Rowe, 2004). Equally important is the issue of teacher retention (See Figure 4.3). Replacing any teacher incurs significant tangible costs in terms of recruitment and training a replacement. Less tangible, but as important, is the discontinuity in the school which requires students to develop a new relationship with yet another teacher and considerable effort to be expended by the established staff in inducting any new staff member (Barber & Mourshed, 2007; Leigh & Ryan, 2006; OECD, 2005b).
3 Student learning and engagement with mathematics

In the past twenty-five years, a significant body of research has illuminated how students learn mathematics, and the types of teaching and learning environments that are conducive to such learning. However, the progress that has been made toward providing such environments on a broad scale has been piecemeal at best, and students, broadly speaking, remain disengaged and lack intellectual stimulation in mathematics classes.

This section examines why students are not engaging in the learning of mathematics and why many teachers have not been able to provide environments to achieve this. It examines the conditions that lead to students experiencing different types of feelings during the learning of mathematics (e.g. anxiety, boredom, pleasure, and excitement) and conditions that engage students. The overlapping constructs of student identity, and student resilience, are identified as crucial areas of focus for engaging students with mathematical problem solving activity, improving mathematical performance, developing mathematical literacy, and influencing students’ future mathematical directions.

3.1 Middle Years research

The years of transition from primary to secondary school are a period of significant identity formation for students, in which time they grapple with issues associated with adolescence and their adult futures. This process of identity formation affects their response to transition and to schooling in general. A Victorian project, the Middle Years Research and Development project (MYPRAD) (Tytler, 2004) developed a set of pedagogical principles which were summarised by Tytler (2007a, p. 11):

1. Students are challenged to develop deeper levels of understanding; emphasising student questioning and exploration, and engagement with significant ideas and practices.
2. The learning environment is supportive and productive; emphasising a classroom environment where students feel able to express themselves, take responsibility for and occasionally take risks with their learning.
3. Teaching strategies cater for individuals’ interests and learning needs; emphasising the monitoring and accommodation of diversity, and the encouragement of autonomy as learners.
4. Assessment is an integral part of teaching and learning; emphasising continual monitoring feeding into planning, and feedback designed to encourage students’ self monitoring
5. Teaching practice meets the developmental needs of adolescent learners; emphasising the active engagement of students in their learning, their involvement in decision making, and the linking of classroom learning with local and broader communities.
The transition period can be difficult for a number of reasons, and the middle years pedagogical principles are designed to mitigate some of the negative impacts outlined below. Transition to secondary school can result in reduced autonomy where students who previously enjoyed responsibility as the most senior students in primary school become the youngest in secondary school with little responsibility. This shift in status occurs when adolescents are struggling with identity issues (Erikson, 1968), and the experience of transition can erode student confidence and negatively impact upon their developing identity. Lack of confidence can affect mathematical performance (McPhan et al., 2008; Thomson & De Bortoli, 2008b) and may be intensified by reduced support systems; less access to teachers and reduced capacity of parents to help with mathematics.

Lack of autonomy has been found to lead to alienation from school and mathematics learning in the USA (Marks, 2000) and Australia (Siemon & Moroney, 2001). In mathematics classes where students only memorise and repeat rules and procedures, rather than explore to develop mathematical ideas, they lack control over their learning. Many mathematics classes in Australia and the USA do not require thinking beyond simple analysis (Siemon & Moroney, 2001; Williams, 2005; Wood, Williams, & Mc Neal, 2006), which means that the intellectual quality of mathematics learning is minimal. Students are not required to reorganise knowledge to develop new ideas and consider the reasonableness of the mathematics they generate. There is limited intellectual quality which is one of the four productive pedagogies linked to substantial learning gains (Luke et al., 2003).

The next section provides background on how students learn mathematics and teaching approaches than can support this learning. It then focuses on how students engage with the learning of mathematics through problem solving activity, and why some students resist such activity. Recent research focused on how to overcome this problem is discussed and various findings about factors that influence mathematical performance across the transition years and beyond are linked to this research.

### 3.2 Background to mathematics teaching and learning today

Mathematics has traditionally been a school subject which many students find difficult and some find easy. Even amongst high achieving students, mathematics can be seen as a meaningless set of rules and procedures that do not relate to the everyday world (Erlwanger, 1975; Skemp, 1976). Mainstream mathematics can be experienced as unchallenging and of low conceptual difficulty. This can cause boredom or apathy. In contrast, students who are unable to memorise rules and procedures that have no meaning to them can become anxious.

When different types of mathematical understandings (recall, making meaning, communicating ideas to others) were identified and elaborated as integral to the process of learning mathematics (Skemp, 1976, 1979), a renewed focus on meaning making resulted. ‘Relational understanding’ (Skemp, 1976), or a connected understanding of mathematics that includes knowing why rules work and when to apply them in unfamiliar situations, and ‘logical understanding’ which includes relational understanding and the ability to communicate these ideas to others, became a priority (Skemp, 1979). Relational
understanding and logical understanding underpin ‘mathematical literacy’ which is the ability to use mathematics to make meaning of everyday life and workplace situations. This is also the type of understanding needed by STEM workers on the cutting edge of research design in Science, Engineering, and Technology (Batterham & Miles, 2000).

Problem solving in mathematics has been found to build relational understanding (Schoenfeld, 1985), while the importance of student-student interactions in developing mathematical meanings has been recognised (Edwards & Mercer, 1987; Mercer, 1995), and several pedagogical models have been developed to increase connected mathematics learning in early primary (e.g. Cobb, Wood, Yackel, & Mc Neal, 1992), upper primary (e.g. Lampert, 2001), lower secondary (e.g. Kieran & Dreyfus, 1998), and upper secondary (e.g. Barnes, 2000; Williams, 2002b) mathematics classes.

3.2.1 Social interaction

During this search for appropriate teaching approaches, communities of mathematical inquiry became a focus of attention and ways to develop reasoning ability of students were explored. Students were encouraged to present and justify arguments and think critically about the arguments developed by others (Reid, 2002; Yackel & Cobb, 1996). These communities of inquiry were focused around small group work (Wood, Cobb, & Yackel, 1990), whole class discussions (Cobb et al., 1992), and / or a combination of both (Barnes, 2000; Williams, 1997).

3.2.2 Inclination to explore

Even though appropriate tasks, pedagogy, student-student and student-teacher interactions associated with effective problem solving have been identified and some teachers have tried to implement them, students vary in whether they engage, resist or just comply with the mathematical activity involved. Cobb et al. (in press) examined student identity as a key factor influencing which students did or did not engage with what was considered the activity of a competent student in their mathematics classroom. Active resistance to thinking for themselves and the desire to follow the lead of the teacher has been identified previously (e.g. Anthony, 1996; Barnes, 2003) and raised by teachers as an inhibitor to using problem solving as a learning approach.

It has been shown that resilience in the form of optimism (Seligman et al., 1995) is possessed by students who are inclined to explore new mathematical ideas (Williams, 2005, 2006a). Links between optimism and mathematical performance have been identified in an Australian quantitative study (Yates, 2002), and links between intellectual quality, cognitive and affective engagement and optimism have been identified in case studies in Year 8 mathematics classrooms in Australia and the USA (Williams, 2005). Attribution Theory (Weiner, 1974) contains some overlapping dimensions with the optimism construct, yet does not include a mechanism for change in perspective over time. It is
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therefore important to distinguish between these two theoretical positions. Both theories focus on student orientation to successes and failures and in both cases, positive characteristics include a perception that failure is temporary and able to be overcome by personal effort. Optimism also includes another dimension, which contributes to the mechanism for change. An optimistic child is able to overcome failures and not only finds ways to increase the likelihood of success by overcoming setbacks, but also sees the successes they achieve as pervasive or due to personal characteristics. Thus, if progressive successes can be achieved, the child can become more optimistic but if they are not optimistic, they will not be inclined to explore to overcome challenges to achieve successes. Pedagogy focused around providing opportunities for students to identify small challenges for a start, and be supported (not helped) to achieve them is crucial (Williams, 2005, 2006a).

This section argues it is time to focus on the psychological factors that inhibit student capacity to engage with solving unfamiliar mathematical problems. Factors that engage or alienate students from mathematics are considered in order to develop a cohesive way to understand learning in mathematics classes.

### 3.3 The engaged to learn model

Engaging students in learning rather than alienating them from it relates to flow (Marks, 2000). Flow (Csikszentmihalyi, 1992) is a state of high positive affect during creative activity. It occurs when a student or group of students spontaneously set and pursue their own mathematical challenge and generate new mathematical knowledge (Williams, 2002a). Flow conditions occur when students work just beyond their present conceptual level on a self-set challenge that is almost out of reach.

The Engaged to Learn Model in Figure 3.1 (Williams, 2000) was developed to examine flow conditions during mathematical problem solving. The model has been used to examine engagement with mathematical ideas in senior secondary (Barnes, 2000; Williams, 2000, 2002b), junior secondary (Williams, 2005) and upper primary (Williams, 2007) classes.

The horizontal axis on Figure 3.1 represents skills and concepts, and point A represents the students’ present conceptual level. The thick line on the horizontal axis beyond A represents the Zone of Proximal Development (1978) that has been spontaneously created by a student or group (Vygotsky, 1933/1966). The vertical axis represents the level of intellectual challenge the student or group spontaneously set rather than a challenge imposed by the teacher. M is the level of challenge a student can comfortably overcome. The black arrows leading into challenges and conceptual knowledge presently out of reach represent student inclination to explore.

Various affective states occur under different conditions represented in the Engaged to Learn Model. These conditions include (a) the relative positions of the concepts the task requires and the present conceptual level of the student; (b) the relative magnitudes of the task challenges and challenges the
student can overcome; (c) whether or not the challenge was spontaneously set by the student/s; and (d) student inclination to explore.

Figure 3.1: The Engaged to Learn Model (Williams, 2000, 2005): Diagrammatic representation of conditions for flow and other affective states during the learning of mathematics.\(^\text{10}\)

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\(^\text{10}\) Synthesises theories of (Csikszentmihalyi, 1992; Hershkowitz, Schwarz, & Dreyfus, 2001; Krutetskii, 1976; Seligman et al., 1995; Vygotsky, 1978; Williams, 2000)
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If in tasks set by the teacher the mathematics required is too easy, and the challenges associated with the task are too small, students can become apathetic or bored. If the challenge or the conceptual level to be attained is too great, the student can become anxious and if both the challenge and the conceptual level are too great, the student can panic. Martin and Marsh (2006) have identified these types of affect as motivation guzzlers.

As different students have different mathematical backgrounds (different positions of A in Figure 3.1), and different levels of challenge that they can easily overcome (different positions of M), tasks need the potential to be accessed different ways so that all students have opportunity for flow conditions that can lead to excitement and pleasure (e.g. Burton, 1999). If students have approached the problem in different ways and can share their findings with the rest of the class, a connected understanding of the mathematics involved can develop (e.g. Cobb et al., 1992). As students progress along the horizontal axis from A to B, their knowledge increases and they are no longer in flow unless they spontaneously focus on another challenge and develop conceptual knowledge in the region BC. This knowledge development through intellectual activities has been the focus of research over the last thirty years (e.g. Krutetskii, 1976).

Optimism, which is examined in more detail in Section 3.4.1 is required to traverse the black arrows in Figure 3.1 and move into unknown territory. Social aspects of the classroom environments that provide opportunities for students to set their own challenges during problem solving activity are complex and relate to the ‘spontaneous’ aspect of the vertical axis in the Engaged to Learn Model. Luke and colleagues (Luke et al., 2003) described a supportive classroom environment including student direction, social support, and academic engagement. Social support (Luke et al., 2003) involves respect for each other in the classroom. Alrø and Skovsmose (2004) describe mutual respect between teacher and students as an equality of interaction in student-teacher discussions.

A dialogue maintains equality including a respect for diversity. This does not mean that a dialogue presupposes similarity or symmetry. We are speaking of interpersonal equality and human respect. In dialogue there should be no use of power or force, no persuasion of the other and no winning. ... to be productive, a dialogue develops as a dynamic process between equal communicating partners. ... Even when the teacher is a more knowing or competent party to the dialogue, classroom conversations can be dialogic. The roles can be different and so can the competencies (Alrø & Skovsmose, 2004, p. 41).

Interactions where students’ ideas are valued and the teacher’s focus is on asking questions to develop these ideas is integral to providing spontaneous learning opportunities (e.g. Lampert, 2001).

Providing such environments is not easy (Wood et al., 2006). There can be a confusion between behavioural autonomy and cognitive autonomy with teachers believe they have provided an appropriate environment for exploration when students have behavioural autonomy. Behavioural autonomy can exist without cognitive autonomy during problem solving activity. For example, teachers can overgeneralise providing emotional security to providing cognitive security and ‘tell’ rather than let
students struggle with unfamiliar ideas (Williams, 2005) and thus lower the conceptual complexity of the task (see Stacey, 1997).

Optimism building is presently being undertaken in a whole school approach at Geelong Grammar where Martin Seligman (2008) has been working with staff and students this year. He will be working with government schools in Victoria in early 2009. Seligman has found that optimism builds when students have opportunities to engage in flow situations because they achieve successes through their own efforts during this process. Thus, the Engaged to Learn Model (Figure 3.1) provides a way to consider factors associated with engaging students with the learning of mathematics, and increasing student inclination to traverse the black arrows is associated with optimism building. This model has been used to identify optimism-building situations in mathematics classes (Williams, 2007) using Seligman’s dimensions to examine inclination to explore.

### 3.4 Engagement in mathematical problem solving

Flow experiences develop deep mathematical understanding accompanied by high positive affect. They have similar features in primary and secondary settings (Barnes, 2000; Cobb et al., 1992; Groves & Doig, 2004; Kieran & Guzmán, 2003). They include students working in problem solving situations to develop mathematical ideas prior to a new topic being taught. These problems have multiple solution pathways and generally more than one possible solution. Students select the mathematics they use to explore the problem, and the pathways they take. The classrooms culture includes an expectation that students will justify the statements they make, and that others will think critically about what is said and query mathematical ideas presented by others where this is appropriate (Yackel & Cobb, 1996).

Student engagement with mathematics occurs where students have autonomy over their learning, and work in an environment where teachers have faith in their ability to succeed (Lockhart, 2002), and are able to support their idiosyncratic explorations. This section examines conditions necessary to engage students in mathematical problem solving including: a) the nature of the inclination to explore; b) identifying mathematical complexities within tasks; c) the intellectual quality in overcoming a mathematical challenge; d) the new mathematical understandings developing; and e) stimulating teacher change.

#### 3.4.1 Inclination to explore (resilience or optimism)

Mathematical problem solving involves coping with many failures before a success. PISA 2006 showed that:

students who are confident in their own abilities and well motivated tend to do better at school. Positive approaches not only help to explain student performance
but are also themselves important outcomes of education (Thomson & De Bortoli, 2008a, p. 15).


Martin (2003a, 2003b) and Martin and Marsh (2006) studying motivation, and Williams (2003, 2005, 2006a, 2006b) studying inclination to explore, identified similar constructs associated with student capacity to overcome adversities associated with learning. Martin’s ‘academic resilience’ is linked to student participation in school learning in general and Williams’ optimism (from Seligman et al., 1995) is linked to student inclination to explore unfamiliar mathematical ideas. Seligman’s optimism is associated with how students explain their successes and failures to themselves. It contains three dimensions: ‘permanent-temporary’, ‘personal-external’, and ‘pervasive-specific’ dimension. These dimensions are illustrated in the examples below.

Increasing optimism can bring about change in student inclination to explore. An optimistic child perceives successes as ‘permanent’, ‘pervasive’, and ‘personal’ and failures as ‘temporary’, ‘specific’, and ‘external’. These characteristics were displayed in interviews of students who creatively solved problems to develop new mathematical ideas (Williams, 2003) through statements like:

a) “it always takes me a long time to understand when we first start a new topic” [failure as temporary];

b) “I go over and over it until it makes sense” [success as personal];

c) “and then I get it” [success as permanent]; “[I could not find the total angle because] I was facing the [angle] points up and out when they needed to face in” [failure as specific];

d) “last year I did not do as well in maths; the teacher took too big a leaps” [failure as realistically external when the comment is made by a student identified as gifted];

e) “I am good at working things out for myself” [success as pervasive].

These dimensions fit factors Martin (2003a) identified within academic resilience:

a) ‘self-efficacy’ (equated to confidence) fits with the perception of success as pervasive;

b) ‘persistence’, illustrated by “If I can’t understand my schoolwork at first, I keep going over it until I understand it” (Martin, 2003a, p. 46) fits with failure as temporary and success as personal.

Martin’s findings (large-scale quantitative study) link these factors with higher school performances thus adding strength to the need to find out more about how building optimism could increase academic performance, as well as increase cognitive and affective engagement. ‘Academic resilience’ does not appear to include failure as specific, which is crucial to problem solving activity. because of the differences between the nature of the constructs. Building student optimism is crucial to increasing
student inclination to engage in problem solving activity, and engaging in problem solving activity can lead to deep mathematical understanding, and positive engagement with mathematics.

Optimism building occurs through successes during flow situations and gaining success in contributing ideas to class development of new knowledge (Seligman et al., 1995; Williams, 2008). Intensity, excitement and pleasure can accompany new insights (Barnes, 2000; Burton, 1999). Building optimism also strengthens mental well being (Glover, Burns, Butler, & Patton, 1998; Seligman et al., 1995) which means this construct is important for the development of adolescents beyond their mathematics learning as well.

Sfard and Prussak (2005) found migrant students in Israel were generally more persistent when trying to overcome mathematical difficulties and had more focused mathematical aspirations than students who had grown up in Israel. They linked these qualities with the narratives these students told about themselves and others. Further research is required to make clear links between the identity construct described by Sfard and Prussak and optimism. Descriptions of the hardships these students had overcome prior to arriving in Israel would suggest these students developed optimism through coping with adversity and that this optimism may have built further during their successes resulting from their perseverance with problems they encountered in mathematics. Cobb and colleagues (in press) considered personal mathematical identity in terms of participation in the normative activity of the classroom. They found students varied in whether they engaged with, complied with, or resisted such activity. Links between students’ mathematical identities and optimism are focused around participation in mathematical problem solving.

### 3.4.2 Opportunities to find mathematical complexities within tasks

The design of the task can limit or promote opportunities for intellectual and affective engagement. Authentic tasks are those tasks which are not just set in a real world context but contain real world contexts that are meaningful to the students and that are likely to engage them in actively exploring mathematics associated with that context (e.g. Barnes, 1994, 2003; Clarke, 2001; Galbraith, 2006; Galbraith, Stillman, & Brown, 2006; Holton & Thomas, 2001; Howard & Perry, 2007; Stillman, 2004a; White & Mitchelmore, 2004). The crucial role of meaningful context is exemplified in Howard and Perry’s study of tasks that engaged Aboriginal students because they were related to their environment and things within it that had purpose to these learners. Galbraith, Stillman, and Brown’s elaboration of student engagement in mathematical modelling to solve real world problems that involved experimentation to find optimal solutions, also illustrates exploring meaningful tasks. In these tasks, students engage with meaningful situations within their environment and select appropriate mathematics to solve the task. In doing so, they link mathematics with real world experiences and see its usefulness beyond school. Tasks can also be engaging because the mathematical complexities students discover within them can stimulate exploration to make meaning of these complexities (e.g. Lampert, 2001; Williams, 2000, 2002b, 2007).
3.4.3 Intellectual quality

In both primary and secondary schools, there are teachers who use problem solving and project work to varying degrees as part of their mathematics classes. The extent to which this improves the intellectual quality of the mathematics lessons (Luke et al., 2003) depends upon factors such as whether: a) activities occur before or after a topic has been taught; b) students work together or alone to develop ideas; c) the teacher reduces the cognitive load by ‘telling’ or agreeing with pathways taken, or encourages students to justify ideas for themselves; and d) the teacher has faith that students will be able to solve unfamiliar challenging problems for themselves, or believes that students cannot solve unfamiliar problems (different teacher expectation) (e.g. Oakes & Lipton, 1996).

Intellectual quality is not about the sophistication of the mathematics used but rather the types of thinking undertaken during the process of developing new mathematical concepts. This type of thinking is represented by the intellectual challenge to be overcome on the vertical axis in the Engaged to Learn Model. It can occur through a process of argumentation in whole class or small group settings (e.g. Ball & Bass, 2000; Vincent & Stacey, 2007; Yackel, 2001). This process includes students considering whether the mathematics generated is reasonable, why it works, whether it is consistent with other mathematical ideas held, and whether it can be used for anything else. Types of thinking that have been identified within these processes include:

- Conjecturing (e.g. Ball & Bass, 2000; Lampert, 2001)
- Analysis (Krutetskii, 1976; Williams, 2007; Wood et al., 2006)
- Synthetic-analysis; two or more ideas considered simultaneously (Hershkowitz et al., 2001; Krutetskii, 1976; Williams, 2007; Wood et al., 2006)
- Evaluative-analysis; reasonableness of mathematics generated considered (Williams, 2007; Wood et al., 2006)
- Synthesis (Hershkowitz et al., 2001; Krutetskii, 1976; Williams, 2005) including finding why patterns work
- Evaluation including considering the fit between previously known mathematics and new mathematical ideas, and considering limitations (Krutetskii, 1976; Williams, 2002b)

Justification and generalisation are parts of several of these thought processes. Use of technology with complex tasks has been identified as one way to stimulate student connection of mathematical representations and deepen student understandings (J. Brown, 2005; Goos, Galbraith, & Renshaw, 2002). That said, there are many instances where technology is used in less appropriate ways and substantial learning does not result.

Pedagogies that can support and elicit such thinking are crucial to improving the intellectual quality of mathematics classes. Links between structuring questions students ask themselves (Cifarelli, 1999) and questions of a similar type teachers could ask when students are not yet able to do so (Williams, 2005)
could be a productive addition to teaching practice. This type of pedagogy is not easy to develop and teachers need time to experiment with and work with these ideas (J. Anderson, 2005; MERGA, 2007). The distinction made between cognitive engagement and such engagement accompanied by affective engagement (S. Helme & Clarke, 2001) helps to elaborate what is required for optimism building which includes affective engagement.

### 3.4.4 Developing mathematical understandings

Oral and written communication of the ideas developed can assist in crystallising ideas. Such thinking has been called variously ‘working mathematically’, ‘mathematical argumentation’, and ‘complex mathematical thinking’ and is associated with the development of mathematical insights (Ball & Bass, 2000; Barnes, 2000; Cobb, 1999; Cobb et al., 1992; Williams, 2002a; Wood et al., 2006). As previously discussed, students develop new concepts by actively reorganising their knowledge. Considering this process as recognising, building-with, and constructing, Dreyfus, Hershkowitz, and Schwarz (2001) provide a useful tool for identifying mathematically significant interactions in class. Recognising involves the student identifying mathematics they already know which could be useful in this situation, and building-with involves using this mathematics in unfamiliar sequences and or combinations to explore the problem. Constructing is the process of developing insights as a result.

Findings about the development of deep mathematical understanding through problem solving informed changes in the senior mathematics curriculum in the Victorian Certificate of Education designed and piloted in the late nineteen eighties and implemented in the early nineteen nineties (Victorian Curriculum and Assessment Board, 1989). The criteria for assessment of these challenging problems related to developing mathematical argument, drawing and evaluating conclusions, and communicating findings to others (Victorian Curriculum and Assessment Board, 1992a, 1992b).

### 3.4.5 Stimulating pedagogical change

The introduction of projects and unfamiliar challenging problems in external assessments that affected university entrance drove curriculum change further down the school (Barnes, Clarke, & Stephens, 2000). Problem solving became a greater part of junior secondary classes and in some cases even began to occur at the beginning of topics where opportunities for flow situations are more likely (e.g. Peck & Barnes, 1999). Through this process, students learn to select appropriate mathematics to use in unfamiliar ways instead of the teacher telling them which mathematics to use and how to use it. This develops mathematical literacy which includes recognising appropriate mathematics in unfamiliar contexts and using it to solve problems in workplace, leisure, and everyday situations (Kilpatrick, 2002).
3.4.6 **Summary**

Where students have the optimism to explore unfamiliar mathematical territory, the task provides opportunities for them to find complexities they want to pursue, and they have the autonomy to accomplish this, they can spontaneously follow their own directions, using background knowledge to access the task, and sometimes dynamic visual displays such as those facilitated by technology to develop the required background. By doing so they can engage in flow situations that can lead to intensity, and excitement during the development of new mathematical knowledge. These are the conditions needed to engage students intellectually and affectively in mathematics learning and increase their future participation in such activity and hopefully their future STEM engagement. Lack of optimism created by the absence of opportunities to build it can lead to students resisting problem-solving activity. The Engaged to Learn Model provides conditions within which optimism can be built and conditions that create apathy, anxiety, panic, and boredom that do not include optimism-building situations. Pedagogical change can be stimulated through changes to the nature of high stakes assessment but long term support is required to realise these changes.

3.5 **Mathematics transition across the primary-secondary divide**

This section looks at factors associated with transition and shows that they are not always clear-cut. It includes an analysis of: (a) shifts in how mathematics is taught; and (b) achievement across the transition years; and how these factors can influence student optimism.

3.5.1 **Shifts in Approach from Year to Year**

There is no one approach that can be used to describe the learning of mathematics in primary or in secondary settings in Australia. Instead, there are a variety of approaches used in each type of schooling, and a variety of reasons for why these approaches are used (J. Anderson, 2005; Barnes, 2000; Bobis et al., 2005; Cheeseman & Clarke, 2007; Clarke, 2001; Galbraith, 2006; McPhan et al., 2008; Siemon & Moroney, 2001; Stacey, 1997; Sullivan & McDonough, 2007). It would appear that for most students there will be at least one stage in their mathematics education in which their learning moves from focus on concrete aids and activity and / or the inclusion of authentic tasks to a transmission approach where students are given rules and procedures and asked to practice. This transition may occur around middle primary school or earlier, at the start of high school, or somewhere later in high school. It is also possible that as students move from class to class, they may shift backwards and forwards between activity based pedagogy and authentic tasks and an approach based on learning rules and procedures.
Although mathematics in lower primary school is generally more ‘hands on’ and students use concrete aids to assist them in understanding mathematical ideas, this use of hands on material is not necessarily a focus of upper primary mathematics education. Lower secondary mathematics education may or may not be activity based or include authentic tasks depending on the school, the teacher, and curriculum and implementation decisions of the school. The use of activity based learning and authentic tasks does not necessarily result in deep mathematical thinking. There are some teachers whose approaches to activity-based learning and authentic tasks is accompanied by a focus on mathematical thinking at the lower primary (e.g. Cheeseman & Clarke, 2007), upper primary and lower secondary (e.g. R. Brown & Redmond, 2007; R. Brown & Renshaw, 2006; Kieran & Guzmán, 2003) and upper secondary (e.g. Barnes, 2000; Galbraith et al., 2006) levels. As previously stated, this depends upon the way it is implemented. Williams (2007) provided an illustration of activity based learning in upper primary school accompanied by deep mathematical thinking and the application of Dreyfus, Hershkowitz, and Schwarz’s (2001) model to that thinking.

In most cases, upper secondary mathematics is taught through a transmission approach although this is not always so (e.g. Peck & Barnes, 1999). There are upper secondary classes where deep understanding of calculus has been developed through group work interspersed with whole class reports of progress and cognitive and affective engagement during such processes has been identified (Barnes, 2000; Williams, 2002a). Real life applications of relevance and interest to students have also been used to capture student interest in senior secondary mathematics and contribute to their development of mathematical literacy and understanding of mathematics (Barnes, 1994, 2003; Galbraith, 2006; Galbraith et al., 2006; Stillman, 2004a; White & Mitchelmore, 2004). Technology has been used to increase mathematical understanding by giving students opportunities to connect various mathematical representations (e.g., graphical, tabular, algebraic) (J. Brown, 2005). Opportunities to interconnect across representations have been found crucial to the development of mathematical insights (Hershkowitz et al., 2001).

In either primary or secondary settings, students may be learning mathematics through a traditional approach where teachers present rules and procedures and students practise, or a combination of this approach with the inclusion of unfamiliar problems set at the end of the topic that involve applying the mathematics just covered, or unfamiliar problems set at the start of a topic to help students develop mathematical ideas before the topic is formally taught. These unfamiliar problems set at the start of the topic are more challenging because the student needs to scan their prior mathematical knowledge to decide what is relevant as long as the teacher does not ‘tell’ what mathematics to use. Thus, the placement of the task and the type of task are not sufficient to ensure intellectual quality (Luke et al., 2003). Intellectual quality has been recognised as one of the four Productive Pedagogies associated with learning gains in Australian schools. It is however underrepresented (Wood et al., 2006) even in the classes of teachers who are seen to be good teachers by their school communities (Williams, 2005) because the teachers reduce the complexity of the task by telling the students what mathematics to use and whether they are right or wrong.
Where students are shifting back and forward between different mathematics learning approaches they spend some time in classes where optimism may be reduced because their learning is not autonomous and they do not have opportunities to work just outside their present conceptual level on self-set challenges that are almost out of reach. The Engaged to Learn Model shows the range of affective states that may exist under different learning conditions. In classes where students have opportunities to explore and can select a level of challenge they are comfortable with, optimism can build through students’ progressive inclinations to try to overcome greater challenges as a result of their prior successes.

3.5.2 Achievement across the transition Years

This section focuses on the nature and content of what we teach and assess across the middle years, student performances on such assessments, the value of the information gained, and effects this type of testing can have on student inclination to explore mathematical ideas.

3.5.2.1 What type of thinking are we testing?

Student achievement in mathematics is generally measured by classroom tests consisting mostly of procedural questions very similar to those in the exercises they complete in class. Such instruments are not testing student capacity to think mathematically but their ability to remember and apply. Tests like the AIM test (Achievement Improvement Monitor) and NAPLAN (National Assessment Program) focus more on rules and procedures rather than on unfamiliar problems involving more than analysis. Even international benchmark tests like TIMSS (Trends in International Science and Mathematics Study) are based predominantly on questions that students can answer by applying rules and procedures. Principles of Learning and Teaching (PoLT) (see www.broken creek cluster.com/ Blueprint/PoLTinfo.doc) are in conflict with the idea of ‘teaching to the test’ but there is pressure for teachers to prepare students for these tests and this can be counter productive to providing high quality learning. PISA is a recent attempt by the OECD to test more than just rules and procedures. This test includes items designed to assess student capability to solve unfamiliar problems and may be productive in changing the nature of what it means to ‘teach to the test’.

Tests students undertake in school include teacher tests, national tests, and international tests. It has been shown that students who achieve high scores on such tests cannot necessarily choose which mathematics to use in unfamiliar situations because they do not always understand the meanings of those things they can reproduce (Haney, 2000, Part 6, p. 10). A lack of ability to spontaneously pose problems and select appropriate mathematics to solve them was also found in engineers in Singapore even though their international test results at school had been high (oral feedback by Berinder Kaur in the session where the following paper was given: (Forgasz, Leder, & Kaur, 1999). Students achieving high scores on tests do not necessarily have the ability to undertake higher order mathematical thinking
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(Amrein & Berliner, 2002; KLein, Hamilton, McCaffrey, & Stecher, 2000). This depends upon the nature of the tests they undertake.

Decreases in student performances on tests on transition from primary to secondary school are unlikely to demonstrate a decrease in ability to think mathematically because this is not what most tests are assessing. It is more likely that this decrease reflects forgotten rules and procedures that were probably not understood and lack of recognising mathematics they have seen before in the differing contexts of primary and secondary school learning (Skemp, 1976). Poor performances by students on these tests could be perceived as failures that they cannot see a way to overcome, particularly if there is no one at home to assist them (see Brew, 2000) and they have little access to their mathematics teacher. These are optimism reducing situations.

Thus, in considering student performances on mathematics tests, it is important to be clear about what is being tested and its relevance for STEM. For STEM careers, students need to develop a deep and connected understanding of mathematics that will enable them to use it in unfamiliar ways when solving non-routine problems (Batterham & Miles, 2000; Kilpatrick, 2002). This involves recognising what mathematics is appropriate and being able to interpret the result of applying that mathematics. It can include developing new conceptual ideas to best address the problem at hand. These are the types of mathematical capabilities we need to develop in ‘ideas workers’ who will be on the cutting edge of Engineering, Science, and Technology research design in the future (Batterham & Miles, 2000). These same ways of thinking mathematically are also required by others in STEM careers and by members of the community who need mathematical literacy in their everyday lives and in their workplaces.

Where mathematics is taught as rules and procedures for the purposes of passing tests (Herman & Golan, 1993) that are only set to test rules and procedures, we continue to condition a shallow learning syndrome identified as a common aspect of mathematics learning in Australia (Stacey, 1997) and student engagement with mathematics remains low. The ways in which shallow coverage has been found to occur include teaching a lot of content, and ‘telling’ answers during problem solving thus reducing the intellectual quality of the learning (Darling-Hammond, 2000; Williams, 2005).

3.5.2.2 Could reducing content lead to a focus on deeper mathematical thinking?

The quantity of content in the school mathematics curricula is too great for students to engage in depth with the mathematical topics (Lockhart, 2002; Saxe et al., in press). In line with this, the National Mathematics Advisory Panel in the USA has recommended that the “mathematics curriculum in Grades Pre K–8 should be streamlined and should emphasize a well-defined set of the most critical topics in the early grades” (2008, p. xvii) and that it should be sequenced so the mathematical ideas build over time (to be coherent). It should be ‘focused’, meaning that the students should engage in depth.

By the term proficiency, the Panel means that students should understand key concepts, achieve automaticity as appropriate (e.g., with addition and related subtraction facts), develop flexible, accurate, and automatic execution of the standard
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algorithms, and use these competencies to solve problems (National Mathematics Advisory Panel, 2008, p. xviii)

Thus, this deeper thinking includes the process of creatively developing conceptual knowledge, and rigorous, rapid, and accurate application of known mathematics.

Darling-Hammond (2000) states that higher achieving countries on international tests in general tend to teach less mathematical content in a year and teach it more deeply than tends to be true in the USA. She states that such countries generally ask their students to solve more real world problems in mathematics and to defend the positions they take (Darling-Hammond, 2000). This finding was not supported with examples and has not always been the findings of others including researchers from the International Learners’ Perspective Study of Year 8 classrooms in Japan, Hong Kong, China, Germany, USA, Australia, Philippines, Israel, Sweden, and South Africa (Clarke, Keitel, & Shimizu, 2006). Leung’s (2001) descriptions of how East Asian students learn mathematics does not fit with Darling-Hammond’s statement either.

3.5.2.3 Mathematics education in Finland (optimism building)

Considering mathematics education in Finland may shed some light on what is important for mathematics learning to occur. Finland scored highly in mathematics in the latest OECD study (Gamerman, 2008; OECD, 2007b). This may at first seem surprising when the culture of mathematics learning in Finland is considered. Closer analysis of this process is informative. In Finland, different to many other OECD countries:

High-school students … rarely get more than a half-hour of homework a night. They have no school uniforms, no honor societies, no valedictorians, no tardy bells and no classes for the gifted. There is little standardized testing, few parents agonize over college and kids don't start school until age 7.

There is little pressure on students to meet external education goals and parents do not show concern over which is going to be the best educational institution for their child. In other words, there is not a constant demand for students to achieve highly and compete with each other. School is not regimented and does not explicitly reward the highest achievers.

Finnish educators believe they get better overall results by concentrating on weaker students rather than by pushing gifted students ahead of everyone else. The idea is that bright students can help average ones without harming their own progress (Gamerman, 2008). This goes against Luke’s identification of the need for intellectual quality and is contrary to the Engaged to Learn Model where students are working on self-set challenges beyond their present conceptual level rather than work they know whilst tutoring another. Differences between Finnish education and these models need further consideration. What is happening in Finland, and what can we learn from this?

The reasons for the high scores by Finland were attributed to:
Well-trained teachers and responsible children. Early on, kids do a lot without adults hovering. And teachers create lessons to fit their students. “We don't have oil or other riches. Knowledge is the thing Finnish people have.” (Finnish high school principal: Gamerman, 2008)

It seems that student autonomy, a differentiated curriculum, and a valuing of knowledge over material things are key features of Finland’s successes with mathematics education and these are optimism building features.

3.5.2.4 Factors affecting performance

Factors that can affect performance include motivation (Martin & Marsh, 2006: large scale statistical), confidence and mathematical background (Thomson & De Bortoli, 2008b; Thomson & Fleming, 2004a; 2004b: large scale statistical), optimism (Yates, 2002: statistical), other affective factors (Grootenboer & Hemmings, 2007) and socio-economic status (SES). Family variables can play a large part in student performance and motivation in mathematics learning (Byrnes & Miller, 2007; Cai & Moyer, 1999). Brew’s study (2000) suggests that better relationships focused around the learning of mathematics can develop when the mother returns to study involving further mathematics learning. Low level of knowledge before entering school can also affect mathematical performance and there is a suggestion that this could be improved through certain preschool programs, however more research is required to confirm these results (National Mathematics Advisory Panel, 2008). What is clear is that parents’ relationships with their children can affect learning and good relationships can lead to learning gain. Brew’s research on the mother as a role model for persistence and Yan and Lin’s research benefits where parents are involved their children’s learning and build good relationships with them (Yan & Lin, 2005) suggest that these children are experiencing less optimism-decreasing situations associated with being told they are dumb, or lazy, or other pervasive descriptors when they do not succeed.

Students’ engagement with mathematics can be affected by continual failures on tests about mathematics they do not understand and do not have a way to work out. Given these potential optimism-reducing factors, the benefits of state-wide and international testing that is focused mainly on rules and procedures needs to be balanced against the detrimental effects they can create.

3.5.3 Problem solving and mathematical rigour

The National Mathematics Advisory Panel (2008, p. xv) in the USA in their report in March 2008 have emphasised the need for students to learn mathematics in ways that develop “mutually reinforcing benefits of conceptual understanding, procedural fluency, and automatic (i.e., quick and effortless) recall of facts.” This emphasises the important point that learning through problem solving and exploration does not mean reducing the rigor of mathematics. It means having a deep understanding of the rules and skills applied so they can be ‘unpacked’ when necessary to make decisions about how to
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proceed in unfamiliar situations. This involves the use of a variety of teaching approaches at different stages in the development of a new mathematical topic. Well-taught Japanese classrooms that were a focus of the international Learners’ Perspective Study show sequences that begin with work on an unfamiliar problem and end with exercises associated with applying the rules and skills developed (Shimizu, 2002).

### 3.6 Denied STEM opportunities

This section examines the unequal opportunities that can be available to different groups of students and considers possible ways to give every student an equal opportunity to succeed in STEM.

#### 3.6.1 Streaming / tracking / setting perpetuates disadvantage

Streaming practices have negative effects on performances of students in the lower streams (Darling-Hammond, 2007; Oakes & Lipton, 1996) and research findings differ in relation to benefits for high ability students ranging from little benefit (Boaler, Wiliam, & Brown, 2000; Clarke & Clarke, 2008) to benefit where the curriculum is differentiated (Kulik & Kulik, 1991). International testing has shown that ability grouping has an overall negative effect on student performance (Clarke & Clarke, 2008). Streaming perpetuates social categories and negatively impacts upon student participation rates in mathematics later in their education (Clarke & Clarke, 2008; Oakes & Lipton, 1996; Watt & Bornholt, 2000).

Tracking decisions are generally made on the basis of tests that assess only a very narrow range of students’ mathematical abilities and lower track students do not have the mathematical background knowledge to score highly on these tests due to lack of opportunities to learn through continual placement in low streams (or tracks). Rarely do these students have opportunities to talk about what they know (Clarke & Clarke, 2008; Oakes, 1985) thus they have less access to “knowledge engaging experiences” (Oakes & Lipton, 1996, p. 170). They are exposed to less problem solving and inquiry, and less emphasis is placed on concepts. In addition, there are differences in curriculum coverage and students in low streams are often not exposed to symbolling and language used in tests.

A much larger proportion of minority students are in lower track classes than the proportion of minorities in the community. With the same test score as a non-minority student, the minority student may be allocated to a lower track if their parents lack the ‘know how’ and status to apply pressure for their child to be the one allocated to a higher track (Darling-Hammond, 2007; Oakes & Lipton, 1996).

Higher track classes tend to have less discipline problems, higher teacher expectations, more highly qualified teachers, a rich rather than “thin, skills-based curricula” (Oakes & Lipton, 1996, p. 169) and
more resources. Students without such benefits fall further behind thus perpetuating the cycle of disadvantage.

Affective factors associated with devaluing low-track students also occur (Clarke & Clarke, 2008; Oakes & Lipton, 1996). Students who are continually placed in low tracks “internalise the judgement that they are less able” (Oakes & Lipton, 1996) which is optimism decreasing because failure is perceived as pervasive or resulting from a characteristic of self (Seligman et al., 1995). Students performing at the same level in lower and higher track classes have displayed differences in their attitudes and approaches to mathematics. Lower track students “feel less challenged, try less hard, do less homework, and say that their teachers are less likely to ask them to demonstrate understanding” (Oakes & Lipton, 1996, p. 178). They experience more motivation guzzlers (Martin, 2003a) because of the boredom or apathy (see Engaged to Learn Model) associated with lack of challenge. Streaming students early in their education exacerbates these differences in opportunities and becomes a process of structuring inequality. Placing minority students in higher tracks has been found to improve their performances (Oakes & Lipton, 1996) as illustrated by the American initiative of ‘shipping’ talented minority students to predominantly white schools.

There are many disadvantages to streaming, for students in the lower stream. These include the provision of a curriculum lacking challenge, decrease in material coverage, greater discipline problems, and a devaluing of these students. Pressures from more articulate parents with more powers of persuasion can lead to an inordinate number of low SES and minority students in these classes. Research has shown that when given the opportunity, students relegated to these classes can achieve more than they do. Such systems structure and sustain inequality.

### 3.6.2 Unethical pressures to raise school results

The impact of schools developing strategies to retain their prestigious place in the community and thus attract high performing students is further disadvantaging lower achieving students by reducing their opportunities to remain in these schools. Many high achieving schools in the US purposely keep low achieving students out of their testing pool by encouraging them to leave school. Low achieving students were found to leave such schools at Year 9 at a high rate where high achieving students were retained (Darling-Hammond, 2007). This could partially explain why high performance in Year 9 is an indicator of later STEM participation. Grade retention, student discouragement, and school exclusion policies have all influenced low achieving students’ opportunities to progress through school (e.g. Darling-Hammond, 2007; Haney, 2000).
3.6.3 Diminished career opportunities for lower track students

Students in lower tracks are less well prepared for mathematics in senior secondary school (Oakes & Lipton, 1996) and teachers are more likely to make course decisions for them (Villegas & Watt, 1991 in (Oakes & Lipton, 1996). In contrast, autonomy in decision-making is encouraged for higher track students (Oakes & Lipton, 1996). Low track students were less likely to realize their career aspirations (Dornbush, 1994 in Oakes & Lipton, 1996), partially due to mistaken views about what career pathways were available through the subjects they took. Lower achieving students in mixed ability Year 8 classes were more likely than comparable students in low track classes to attain their career aspirations.

There are strong arguments for heterogeneous classes rather than streaming and Oakes and Lipton (1996) recommend “a comprehensive set of mutually supportive changes that lead to new ways of thinking as well as new practises” (Oakes & Lipton, 1996, p. 179). To cater for students with varying mathematical backgrounds and paces of learning in the same class, they recommend the same principles identified by other researchers including Clarke and Clarke (2008).

3.6.4 Implications of findings about streaming / tracking / setting

These recommendations made by Oakes and Lipton and reflected in the statements of Clarke and Clarke (2008) fit with an assumption that a student’s ability to learn can improve. Underpinning these changes to teaching and learning is a faith in student capabilities, which is consistent with Williams’ (2002b) findings that we need to have faith in students’ abilities to think mathematically. They also fit with one of the recent findings in “Rising Above the Gathering Storm” (COSEPUP, 2005) which states that “there are two methodologies proven to improve math proficiency: Statewide specialty high schools (e.g., IMSA [Illinois Mathematics and Science Academy]) and inquiry-driven project-based learning”.

Oakes and Lipton’s recommendations can be summarised as follows:

a) Group work with complex problems lasting several lessons and addressing more than one curriculum area;

b) Assessment practices that value a broad range of aspects of learning including skills, conceptual knowledge, and the ability to use knowledge in unfamiliar situations and communicate ideas to others;

c) Links between school learning and situations of interest to students for which the mathematics is found meaningful and useful in solving (Oakes & Lipton, 1996, p. 169) real world problems;

d) Avenues for ‘catch up’ (e.g., extra classes, cross age tutors, after school help, an extra teacher or cross aged tutor in class to provide additional help as needed, and timetabling a ‘double dose’ of mathematics in place of an elective).
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Ways in which such recommendations could be realised are illustrated by recent innovations that need to be researched. As an example, an innovative way to provide ‘catch up’ opportunities has been developed at Kambrya College in Berwick, Victoria where interactive whiteboards and the associated video function capture mathematics lessons that students can access at home to review the lesson.

Patterns of participation of students in groups can influence the collaborative development of new knowledge. Barnes (2003) found different genders were more likely to take up certain combinations of ‘positions’ during group work. She makes recommendations to assist with implementing productive group work in senior mathematics classes. Barnes’ research is supported by findings on patterns of participation affecting group outcomes of Engineering students working on challenging problems (Wood, Hjalmarson, & Williams, in press). The relative optimism of group members also appears to influence group outcomes (Williams, in press). Professional learning for teachers about influences of personal characteristics on group participation and group outcomes could support their use of appropriate pedagogies.

3.6.5 Inequities associated with gender

Bandura et al. (2001) demonstrate that there is a gender bias in teacher and parental expectation of students’ performance, especially in mathematics subjects, and as a result a negative cycle is often perpetuated for female students, who are opting out of higher-level mathematics at a greater rate than male students (see Bandura et al., 2001; Forgasz, 2006a, 2006b). Ability grouping in mathematics, particularly at the advanced levels, tends to have a significantly negative impact on female students’ enjoyment of and interest in mathematics (J. Osborne et al., 1997). However, Forgasz, Leder and Kaur (1999), and Forgasz and Mittelberg (2007) note that perceptions of mathematics as a male domain are largely changing, and the majority of both male and female students in Australia regard mathematics as a gender-neutral domain. Female students tend to prefer the non-competitive nature of collaborative group work and learning that includes understanding so the recommendations made to reduce inequalities in other areas also fit with appropriate learning contexts for female students.

3.6.6 Opening opportunities: Summary

In summary, by addressing the inequalities identified, more opportunities can be provided for late matures to enter STEM pathways. Where students experience a lack of autonomy in decisions about subject choice and how they learn, this can lead to negative learning experiences. Where inappropriate levels of mathematical content, and challenge are provided students can become alienated from mathematics because they become bored or apathetic about mathematics learning, or anxious or panicky because they feel out of their depth. Where students have the autonomy to select their own level of challenge and their own mathematical pathways within an overarching mathematical problem set by the teacher, there is opportunity for deep learning accompanied by high positive affect. This is
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expected to lead to increased interest in STEM. The role of the teacher is crucial. The need to attract high quality teachers and to provide ongoing professional learning for them has been identified as one of the six key elements necessary to develop a foundation for success in mathematics for US students by the National Mathematics Advisory Panel (2008). Optimism is a characteristic that must be built in students to increase their opportunities to engage with STEM by increasing their inclination to undertake exploratory activity. Learning how to build optimism is crucial to developing pedagogy to increase engagement with STEM.

3.7 How to engage to learn mathematics at 14-16 years

Remaining in mathematics at ages 14 to 16 can be influenced by many factors including school based, parental, and career based factors. School based factors include whether mathematics is perceived as an interesting subject that is relevant to the out of school life of the student and can be used as a tool for decision making, whether students have the opportunity to work autonomously to set challenges just beyond their present understanding, and whether they are inclined to engage in such exploration. Parental influences include their capacity to assist their children with mathematics, the relationships they build in doing so, and whether they have faith in their children to be able to achieve. Career based influences include mathematics as the gatekeeper to so many careers. Attending to these factors holds the promise of reducing the alienation of students from mathematics in the middle years of schooling through boredom, disinterest, and anxiety.

Tasks that are engaging and that help to develop deep mathematical understanding have been found to have common features. They occur prior to instruction in a new topic, are conceptual tasks that provide opportunities for student to begin to develop the new topic themselves, have multiple entry points, multiple possible solution pathways and often more than one possible solution. They include opportunities for the whole class to share the findings of individuals or groups, and students or groups have control over the focus they take and the way they decide to pursue the problem.

The development of appropriate pedagogies has been found to occur when time is structured into the school day (rather than tacked onto the end of the day) for teachers to work as teams to reflect upon what is likely to occur with a complex task, decide upon appropriate ways to respond, and come back to the group to discuss what has happened. This process requires the presence of an expert teacher with a research background to draw attention to crucial ideas discussed, and direct teachers to appropriate readings.

Personal characteristics that increase student inclination to explore should theoretically be able to be built during mathematics learning. In doing so, the following student characteristics are strengthened: student persistence (success as personal, failure and temporary and specific), confidence (includes success as pervasive), and ability to look into present lack of success to find what to change to increase likelihood of future success (failure as specific) will contribute to student inclination to take the risks associated with exploring mathematically. Where the teacher controls what the student is to focus on
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and how, where rules without meanings are the focus of attention, and where correct answers rather than the process of learning is the focus of attention there is little opportunity for optimism building and such situations can contain features that are optimism decreasing.

The Mathematics Education Research Group of Australasia submitted a report for the Parliamentary Inquiry into the Professional Learning of Teachers (MERGA, 2007). It summarised the results of a four yearly review of this topic by MERGA (2004-2007). MERGA drew attention to the need to provide professional learning to support the teachers we have, and incentives to keep them in the system. They also identified the need to recruit potentially high quality teachers, and also drew attention to the need for funding to release high quality teachers as mentors and to provide professional learning for others.

Professional learning needs to focus simultaneously on providing the conditions to engage and building of personal characteristics that increase student inclination to explore. Being able to fulfil this role requires that a teacher recognises the significant mathematical statements students make during their explorations and what questions to ask to elicit further exploration of these ideas (MERGA, 2007).

3.8 Focusing professional learning on mathematics pedagogy

This section identifies features of teaching approaches that reduce opportunities for engagement.

1. Learning is not effectively supported if students are unable to exercise conceptual agency: choose methods to use, develop meanings, and make mathematical connections (or optimism, Greeno, Sommerfeld, & Wiebe, 2000).

2. Telling when asked rather than providing opportunities for the cognitive struggle decreases opportunities for students to develop deep understandings, and experience the accompanying positive affect (Lampert, 2001; Lockhart, 2002; Williams, 2005).

3. Where groupings appropriate for peer tutoring are used in situations where the collaborative development of new knowledge is expected, quality learning is unlikely to occur because peer-tutoring groups require the inclusion of at least one student who ‘knows’ and can ‘teach’ the others (Vygotsky, 1978) and collaboration associated with flow conditions involves all students working outside their present understandings.

4. The mathematical background of the students, the relative paces at which they think (Williams, 2002b), the patterns of interactions relating to ‘positions’ students take within groups (Barnes, 2003; Wood et al., in press), and their inclination to explore (Williams, 2003, 2008) are personal characteristics that can influence opportunities to learn in groups. Teacher implementation of group work could be assisted through professional learning on group composition.
5. Teachers’ capacity to listen to student discussions and identify the statements that could lead to exploration of significant mathematical ideas is a crucial aspect of learning through problem solving (Anderson, 2005; Wood et al., 2006). Where this does not occur, the intellectual quality of the lesson is low. Where the teacher can ask questions to encourage students to consider the ideas they develop further (Ball & Bass, 2000; Barnes, 2003; Reid, 2002; Wood et al., 2006), intellectual quality and deep mathematical thinking can result.

Descriptions of how transmissive teaching can stifle creativity and result in boredom and a dislike for mathematics are expressed in Lockhart’s lament (2002). It contains his reflections as a highly regarded research mathematician; now a mathematics teacher across K-12 in a private school in New York. He stated:

If I had to design a mechanism for the express purpose of destroying a child’s natural curiosity and love of pattern-making, I couldn’t possibly do as good a job as what is presently being done— I simply wouldn’t have the imagination to come up with the kind of senseless soul destructing ideas that constitute contemporary mathematics education … The only people who understand what is going on are the ones most often blamed and least often heard: the students. They say, “maths class is stupid and boring” and they are right.

Lockhart captures the senseless nature of expecting students to learn rules and procedures that have no meaning to them, the boredom that results, and the stifling of creativity during the process. He calls for a change that gives students the opportunity to explore and make meaning of mathematics. He emphasises that by taking out the ‘why’ and leaving only the ‘what’, mathematics has been turned into an empty shell. The beauty of mathematics is not in the truth, it is in the exploration or argument to get to that truth and this is what we need to focus on to engage students. (These are the conditions associated with the Engaged to Learn Model). Lockhart makes clear this is not a plea for less rigor but rather for creative thinking to develop the mathematical ideas and concepts that lead to rules and procedures. Whilst problem solving is not being appropriately implemented, many students’ mathematical learning experiences lack the excitement associated with working like mathematicians to learn about the ideas behind the mathematical rules and procedures.

In both primary and secondary settings, teachers need further professional learning to help them to identify and capitalise on highly significant mathematical statements made by students (Wood et al., 2006). It is this knowledge that can promote intellectual quality during the learning of mathematics and can lead to situations in which high positive affect accompanies mathematics learning that could increase student participation in STEM pathways.
4 Student learning and engagement with science

There is widespread concern about the lack of student engagement in science education in Australia and these concerns are shared by other OECD countries. A number of high level reports argue that the problem lies with the poverty of school science education. In this section we will examine the validity of this claim. We will discuss a variety of recent reform movements in science education that have been based on research into student learning and engagement, and consider the extent to which these might explain trends in the STEM pipeline. We will also examine recent literature on student attitudes and aspirations with respect to science that may throw fresh light on the problem with participation. Our focus will be guided by an investigation of whether or not current traditions in school science teaching and learning are adequate in late modern societies.

4.1 Background to science teaching and learning today

Reform movements in science education commonly refer to traditional science classroom practice, and the exclusive focus on delivery of formal content in a way that fails to excite student interest. The basis for reform in science education have arisen from the following research findings:

- students have negative attitudes to school science, and specific populations of students (girls, or indigenous populations) are particularly unengaged;
- students come to classes with prior conceptions that are at odds with scientific formulations, and these preconceptions remain untouched at their core despite successful negotiation of school science tests (See Duit & Treagust, 2003, for a bibliography of this literature);
- the focus on conceptual content fails to adequately represent science as a mode of inquiry, and leads to a failure to engage students in genuine scientific thinking (Goodrum, 2006; Schwab, 1962, 1965);
- the population of students in secondary schools has expanded, leading to calls for a “Science for All” (Fensham, 1985) and for Scientific Literacy as a major driving force (Bybee, 1997), to prepare students as future citizens as well as potential future science professionals;
- school science should better reflect the application of science ideas in social and technological contexts (the Science-Technology-Society movement, Yager, 1996, and Science in Context approaches) and in human contexts (Aikenhead, 2005); and
- traditional school science has failed to adequately represent the changing nature of science as it is practiced in contemporary society (Tytler, 2007a).

This review will briefly interrogate each of these dimensions as possible factors affecting student aspirations in relation to STEM.
4.1.1 Attitudes to school science

There is continuing disagreement on how disinterested middle years students are in science, particularly physical science, compared to other subjects. Some studies (Lindahl, 2003; Stagg, Laird, & Taylor, 2003) emphasise how little school students enjoy physical science in particular, whereas others (Jenkins & Nelson, 2005) find higher levels of interest in science. One reason for such varying diagnoses relates to whether students are asked about science in general, or about particular science strands. Studies agree, however, that a) middle school students perceive the work of scientists as unexciting and not something they can personally relate to (Jenkins & Nelson, 2005; Stagg et al., 2003), and that b) attitudes to science decline over the secondary schooling years.

Australian studies over the last two decades have shown a general decline in students’ interest and enjoyment of science across the middle years, with a particularly sharp decline across the primary to secondary school transition (Adams, Doig, & Rosier, 1991; Goodrum, Hackling, & Rennie, 2001). Speering and Rennie (1996) in a questionnaire and interview study that followed students across the primary to secondary school transition, identified a number of interconnected factors that affected student attitudes. They were:

- the impersonal nature of the teacher–student relationships caused in part by fragmented timetable arrangements;
- a change from an activity-based science program to one dominated by transmissive approaches (involving direct instruction by the teacher with reduced opportunity for discussion); and
- a curriculum that enabled very little tailoring to individual students’ needs.

Speering and Rennie (1996) point out that this decline in interest in the early years of secondary school is of particular concern, since it is in these years that dispositions to pursue science subjects and careers are formed.

The change in student attitude across the transition years is also perceived by teachers. A survey of several hundred Victorian teachers of science (Gough et al., 1998) explored their perceptions of students’ attitudes and interests. Figure 4.1 shows the number of teachers responding to each statement with ‘agree’ or ‘strongly agree.’
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**Figure 4.1:** Teacher perceptions of student attitudes to science

<table>
<thead>
<tr>
<th>Student attitudinal statement</th>
<th>% of teachers who agree or strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
</tr>
<tr>
<td><strong>Students:</strong></td>
<td></td>
</tr>
<tr>
<td>Think science is interesting</td>
<td>70.3</td>
</tr>
<tr>
<td>Are enthusiastic about their science studies</td>
<td>59.6</td>
</tr>
<tr>
<td>Think science is relevant to them</td>
<td>37.5</td>
</tr>
<tr>
<td>Have an out-of-school interest in science</td>
<td>13.6</td>
</tr>
<tr>
<td>Think a career in science would be worthwhile</td>
<td>10.5</td>
</tr>
</tbody>
</table>

Source: Gough et al. (1998) Science baseline survey

The table shows a very clear difference between secondary and primary teachers perceptions of student attitudes towards science.

Students’ negative attitude regarding the relevance of school science for their lives was a strong theme in the report on the status of science in schools (Goodrum, 2006; Goodrum et al., 2001). Many presentations at the ACER 2006 research conference “Boosting science learning – What will it take?” referred to this student negativity either explicitly or as a background to their work (Corrigan & Gunstone, 2007; Fensham, 2006; Goodrum, 2006; Harris, 2006; J. Osborne, 2006; Rennie, 2006; Thomson, 2006). A number of studies have linked this decline in student interest with the nature of the traditional science curriculum and its inability to make science meaningful and interesting to students (Aikenhead, Calabrese, & Chinn, 2006; Fensham, 2006).

Sue Thomson (2006), in a review of the results of the Australian attitude data from the TIMSS 2002 survey (Thomson & Fleming, 2004b), reported reasonably high levels of student self confidence in science although the percentage reporting a ‘high’ level dropped from 66% to 49% between Year 4 and Year 8 students. The proportion of students reporting they like science ‘to some extent’ was 87% for Year 4, dropping to 67% for Year 8. 36% of Year 8 students reported they liked science ‘a lot’. This figure is lower than the international average, and broadly consistent with the trends described above.

One of the problems in interpreting such data is that students’ attitude to schooling generally become more negative across the middle years, Grades 5-9. This will be discussed in the next section with reference to recent research on identity and aspirations. However, there is detailed data on students’ response to science in particular which provide evidence of the need to improve approaches to teaching and learning. Three recent interview studies in particular have provided more detailed insights into what is turning students away from science. The three studies were from Australia (Lyons, 2006a),
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Sweden (Lindahl, 2003) and the UK (J. Osborne & Collins, 2001). Lyons’s (2006a) meta-analysis of the findings of these studies highlighted three major themes:

- the transmissive pedagogy that characterised school science
- the decontextualised content that did not engage students’ interest or commitment
- the unnecessary difficulty of school science.

Lindahl’s (2003) study was a longitudinal design following 80 students from upper primary school to the point where they chose their senior school subjects. She found that students resented the lack of opportunity for personal opinion and expression in science, caused by the narrow range of pedagogies used. They were also not attracted to what she called the semiotics of the classroom: texts crammed with facts and teachers who did not laugh. In her study there were a number of academically strong students with an interest in science that had developed outside school, yet who rejected school science as something very different. She also found that students tended to be consistent in their intended career choices from primary school, and many had no idea what sort of work school science could lead to.

Lyons (2006a) characterised the transmissive pedagogy of science as a feature reported so widely that it seemed to be regarded as an inherent characteristic. Osborne’s and Collins’s (J. Osborne & Collins, 2001) informants talked of ‘right or wrong answers’ with no room for creativity or time to discuss or reflect or offer opinions. They argue that this aspect of school science is a response to an overfull curriculum that is dominated by content. They also found the perceived irrelevance of school science to be ‘a recurring theme’ among students regardless of whether they intended to continue with science study (p. 449). They concluded that teachers too infrequently attempted to link science concepts to everyday life. Students in all studies recognised the importance of science content but nevertheless affirmed its ‘boring’ nature, characterised by Lyons as ‘science is important – but not for me’ (Lyons, 2006a: p. 600).

Aikenhead (2006) argues that there is abundant evidence that traditional school science is not meeting the needs of students. He stipulates that curricula with the characteristics he identifies as “humanistic” science — involving acknowledgment of the social, cultural and human aspects of the scientific enterprise, rather than the traditional focus on canonical knowledge as preparation for science careers — are of more interest. He argues that coming to appreciate science, for many students requires an identity shift whereby they come to consider themselves as science-friendly: ‘to learn science meaningfully is identity work’ (p. 117). We will take up these questions of student attitudes, aspirations and identity in more detail in the next section, drawing on recent perspectives.
4.2 Science transition across the primary-secondary divide

4.2.1 Science in primary schools

Research dating back at least three decades has highlighted the infrequency of science teaching in primary schools in Australia as a critical problem. Science teaching in primary schools “is more honoured in the breach than by its presence” (Speedy, Annice, & Fensham, 1989). Science is usually the first subject to be lost when special events such as swimming or concerts disrupt the normal timetable. This is because science is often the subject that primary teachers feel least confident to teach and many avoid teaching science; because equipment is seen as time consuming and difficult to organise; and because the curriculum is seen as crowded, with literacy and numeracy having a higher priority and being mandated in the early years of primary school (Jeans & Farnsworth, 1992; Skamp, 1991; Tytler, 2001). Anecdotally, science teacher educators regularly report that their primary teacher education students return from teaching rounds not having seen examples of science teaching, nor having been supported to teach science. This accords with the earlier findings of Grindrod et al. (1991).

A survey of studies based on written surveys and/or telephone interviews (Adams et al., 1991; Australian Science Technology and Engineering Council, 1997; Gough et al., 1998; Lokan, Ford, & Greenwood, 1997) mostly indicated a mean time per week spent on science of one hour or slightly less than that. Between 33% and 50% of schools reported more than one hour spent on science. Goodrum, Hackling and Rennie (2001) in a national telephone survey found, on the basis of teacher estimates, that most primary schools in Australia are spending in the range of 30 – 90 minutes per week on science with a mean time somewhat less than one hour. However, they commented that this was likely to be an overestimate, with teachers finding it difficult to distinguish between science and technology, or to estimate time on science within an integrated unit.

Tytler and Griffiths (2003), as part of the School Innovation in Science project, undertook a survey that asked teachers to estimate, across a semester and drawing on records, the number of hours spent on stand alone science, or science within integrated units, or on special events. They identified a variety of ways in which science was included in the curriculum, and found a mean of 3.0 hours. Over a selected term, teachers found the time spent on science doubled as a result of being part of the SIS project. The authors make the point, however, that participating schools were untypical, and possibly unrepresentative, having volunteered to be part of this science initiative. Nevertheless, the point is well made that estimating the amount of time spent on science is not straightforward.

The reality in Australia is that, despite some decades of mandating science in the primary school curriculum, and of state and national projects focused on curriculum resources and/or on teacher professional development, coherent science programs at the primary school level still tend to be the exception to the rule. There are some very good programs running, and teachers dedicated to science who have instituted interesting and exciting activity based programs. It seems that teachers in primary
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schools are on the whole not sufficiently interested or confident in science and its teaching to accord it high priority.

One of the problems with interventions in Primary schools has been their short term nature, with gains made in introducing curriculum resources or special initiatives lost once the intervention has run its course and other priorities take over. To transform this state of affairs requires a significant, sustained commitment focused on teacher capacity. The Primary Connections initiative (Hackling, 2008), which includes exemplary curriculum resources to support teacher professional learning, is based on an inquiry-oriented pedagogical model. It has made inroads into the practice of many schools, but if it were to be implemented at a level sufficient to improve participation nationally, it would need to be explicitly tied to curriculum accountability requirements, and supported by a coherent professional learning intervention over a significant time.

4.2.2 Science and the middle years of schooling

A considerable amount of research has focussed upon student engagement in the middle years of schooling in Australia, and a number of pedagogical principles have been developed for education in the middle years, as described in Section 3.1. The School Innovation in Science project (Tytler, 2005b, 2007b, in press) incorporated middle years pedagogical principles, and these were extended in the Improving Middle Years Mathematics and Science (IMYMS) research project (Tytler, Groves, Gough, Darby & Doig, 2007). The Project for the Enhancing of Effective Learning (PEEL Mitchell, 2007) pioneered strategies to promote higher order thinking, including metacognition. These and other projects have focused on pedagogy as their major lever for reform. The Middle Years Research and Development project (MYPRAD Tytler, 2004) developed pedagogical principles consistent with this research, described in Section 3.1.

Research conducted by Tytler et al. (2003), as part of the MYPRAD project used a student questionnaire to provide a snapshot of teaching practice across discipline areas. This showed low levels of enthusiasm for school science, compared to other subjects, and a view of teaching in science characterised by general disagreement with the statements:

The teacher encourages us to express our ideas and opinions in class discussions; the teacher has a good idea of what my interests are; we study things which are interesting to me; the teacher varies the lessons so we do lots of different types of things; the teacher sometimes gives different types of work to different students; the teacher knows when we understand things well; and we are interested and involved in our learning (Tytler, 2007a, p. 12).

The report raised the issue of whether these pedagogical principles may be more or less appropriate depending on the knowledge demands of particular subjects, but pointed out that there was sufficient diversity of teaching practices within each subject to provide confidence that such principles were applicable across all subjects (Tytler et al., 2003, p. 19).
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Darby (2005), in a study of science students’ perceptions of their teachers impact on learning, emphasises that relational pedagogies, including passion toward science and teaching, providing comfort through friendliness and lack of threat, and support through encouragement and attention, are as important as instructional pedagogies which are perceived to include explanation, discussion and clarification.

Although there is a wealth of qualitative and quantitative data to support these approaches to the middle years of education, as far as we have been able to ascertain there is presently no detailed or quantifiable data on the impact of middle years interventions on student retention and choice. The SIS project in Victoria developed pedagogical principles based on the practice of effective teachers of science (Tytler, Waldrip, & Griffiths, 2004), and found that students of teachers who measured high on these characteristics had significantly more positive scores on a range of attitudinal measures (Tytler, 2005a, in press), and scored higher on standardised tests (although this finding was not consistent across years). The project resulted in substantial change in teacher classroom practice, and significantly improved operation of the science teams in planning and implementing change (Tytler, 2007b). The project found evidence of improved student interest in science and uptake of optional science units at secondary level. However, it proved difficult, in the four years it ran, to identify clear evidence of improved uptake of post compulsory STEM subjects given competing variables such as teacher movement and curriculum change.

From these studies, it seems clear that closer alignment of school science practice with middle years pedagogical principles would improve student engagement and would be an important direction to take in any reform agenda.

4.2.3 Approaches to transition

Part of the focus of middle years reform initiatives has been the nature of school organization and school ethos. Hill and Crevola (1997) developed a set of principles that underpinned the Middle Years Research and Development Research Project in Victoria. Schools involved in MYRAD developed approaches to transition, some of which were taken up by schools in the School Innovation in Science research project (Tytler, 2005b, in press) which worked with networks of primary and secondary schools. These approaches include:

- Links between secondary schools and their feeder primary schools to smooth the transition and reduce feelings of unfamiliarity, such as visits to secondary school laboratories for special science projects, or mentoring of primary students by secondary students;

- Minimizing the number of teachers who interact with students in the first year of secondary school – this sometimes involves the same teacher teaching mathematics and science in ways that allow links to be made (although the demerit side of this can be that subjects are taken by teachers out of their field of expertise);
• A clear and explicit focus on learning principles;

• Particularly in mathematics, diagnostic assessment and special support structures for students struggling with the conceptual demands of the subject;

• Increasing the time for teaching periods, to encourage structuring lessons to vary activities and pedagogies; and

• Transferring and acting upon students’ records as they make the transition to allow greater understanding of prior achievement and individual variation.

### 4.3 Expanding the focus of science teaching and learning

#### 4.3.1 Student conceptions and conceptual change

A major program of research in science education over the last three decades has explored how scientific literacy is gained by challenging and overcoming preconceived ideas. Student conceptions of science that don’t cohere with formal classroom science are persistent and can hinder learning in science classrooms to varying degrees. The key findings of this research are that students come to science classrooms with strongly embedded intuitive understandings that a) are at odds with science conceptions of the world, and b) that tend to persist even when students have gone through substantial courses of study and have achieved good assessment results (Driver, 1989; R. Osborne & Freyberg, 1985; Tytler, 2002). Learning science, at least in regard to the key concepts of science such as energy, force and motion, the nature of materials, the earth in space, and animal and plant adaptation, is thus characterised as a process of conceptual change (Duit & Treagust, 2003). This research has led to substantial revision of how we envisage the planning and implementation of teaching sequences (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Fensham, Gunstone, & White, 1994; Hubber & Tytler, 2004). Approaches that emphasise student conceptual change underpin, for instance, the national curriculum projects Primary Connections (Australian Academy of Sciences, 2005), and the more recent Science by Doing (www.sciencebydoing.edu.au). Conceptual change approaches initially emphasise prior student views, and student exploration of phenomena, before challenging these preconceptions and establishing the scientific view as a more productive explanatory model.

These approaches to science teaching and learning have not been shown conclusively to lead to improved student outcomes, although many interventions based on them show evidence of significant student learning. There is no doubt however that this research, and the experience of these programs, have sharpened our understanding of how students learn key science concepts. The more rationalist versions of conceptual change theory have been the subject of strident critique, on the grounds that it fails to take account of affective and motivational aspects of classroom engagement and learning (Sinatra, 2005). A number of reviews have raised questions about the evidence of success of the classic
conceptual change approach. Tytler (2007a) argued that the focus on canonical content needs to be questioned if we are to meaningfully reform science education:

it has become clear that learning is a much more complex process than is captured by this simple conceptually oriented constructivist/conceptual change perspective on learning. The move away from an exclusive focus on canonical science ideas... also requires a move away from a traditional view of learning as conceptual change, and the development of a more nuanced theory that can capture the contextuality and the attitudinal components of the curriculum (p. 33).

4.3.2 Inquiry based curricula

Inquiry has a long history in the ideas of educators such as Dewey, Bruner and Schwab. Schwab (1962, 1965) famously described the traditional science curriculum as a ‘rhetoric of conclusions’ and argued for a science curriculum that educates students in the way science ideas are posed, experiments are performed, and how data is converted into scientific knowledge. Inquiry teaching has been a strong theme in science education reform in the USA, in Australia, and elsewhere, but its realisation in practice has been far from successful. A national review of science teaching and learning in Australia (Goodrum, 2006; Goodrum et al., 2001) found that teaching of science in Australia was dominated by traditional transmissive pedagogies despite decades of reform attempts. Osborne (2006) emphasised this as an international experience:

Four decades after Schwab’s (1962) argument that science should be taught as an ‘enquiry into enquiry’, and almost a century since John Dewey (1916) advocated that classroom learning be a student-centred process of enquiry, we still find ourselves struggling to achieve such practices in the science classroom (J. Osborne, 2006, p. 2)

In Osborne’s terms, inquiry approaches to school science

serve as signposts to an ideological commitment that teaching science needs to accomplish much more than simply detailing what we know. In addition, there is a growing recognition of the need to educate our students and citizens about how we know, and why we believe in the scientific world view (J. Osborne, 2006, p. 2).

This is not to say that school science teaching should attempt to duplicate the practices of science itself. The two are very different activities. However, representing the evidential processes of science must be a key component of educating both future citizens and science professionals. A shift to inquiry teaching requires a significant shift in teacher beliefs and the development of new skills, and runs parallel with the advocacy of problem solving in mathematics, described in the previous section.

Again, while there are successful outcomes of inquiry teaching reported in many small scale projects, the evidence of large scale shifts in student attitudes or learning associated with inquiry approaches is limited.
4.3.3 Scientific literacy

The improved retention rates in secondary schools means that the curriculum no longer caters only for elite students taking academic pathways. This has led many proponents to argue for a broadening of school science to cater for all students, not merely potential scientists. This perspective includes the Science – Technology – Society movement which emphasises the need to include in the curriculum learning about the interactions between science and technology, and the social uses and implications of science. Fensham (1985) encapsulates this thinking about the need to cater for an expanded set of students in his call for a “Science for All.” The thinking and commitments included under this slogan have since shifted to a call for ‘Scientific Literacy’ (Bybee, 1997; Goodrum et al., 2001) that argues for a focus on the future engagement with science of citizens, as well as of professionals. Developing a definition for the purposes of the PISA 2006 assessment project, Barry McCrae (2006, p. 22), describes scientific literacy as follows:

- scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues
- understanding of the characteristic features of science as a form of human knowledge and enquiry
- awareness of how science and technology shape our material, intellectual, and cultural environments
- willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.

Scientific literacy hinges upon arguments that school science should be expanded so that students can engage with science in their everyday lives. The inclusion of the knowledge and work of engineers and technologists and mathematics professionals arguably represents a broadening of the traditional science curriculum, but the scientific literacy notion presents a greater challenge, and acknowledges that school science should be committed to developing scientific knowledge and competence in all students.

4.3.4 Science in context

A major principle underpinning recent curricula developments is that science learning must be situated in contexts that are meaningful to students. The idea of contextual learning has been around for some time and underpins courses like the PLON physics course or the Salters Chemistry course. Bennett, Campbell, Hogarth and Lubben (2005). In a review of studies involving controlled evaluations of context-based science courses, including an in-depth review of five studies, concluded:
The review has, with some caveats, demonstrated that there is good evidence to support the claim that context-based approaches motivate students in their science lessons … The in-depth review has further demonstrated that there is reasonable evidence to suggest such approaches also foster more positive attitudes to science more generally. The in-depth review also provides reasonable evidence from four of the five studies to suggest that context-based approaches do not adversely affect students’ understanding of scientific ideas. The fifth study indicated understanding was enhanced (Bennett et al., 2005, p. 4).

Similarly, Pilot and Bulte (2006), reviewing articles in a special journal issue on context-based chemistry courses, found evidence of increased personal relevance and the possibility of generating coherent mental schema in such courses. They argued that the issue of transfer of learning needs to be addressed in the design of such courses. It seems therefore there is some evidence of advantage in context based courses, but the effects are not so compelling as to be likely to substantially turn around student attitudes to science. As yet, there is no evidence of effects on student aspirations.

The idea of contextual learning is strongly established in Australian curriculum writing, and was strongly supported in teacher forums run at the 2006 ACER conference on Boosting Science Learning (Tytler, 2007b). Such innovations have at times struck difficulties with traditional assessment regimes that focus on the manipulation of abstract knowledge in set piece situations, and do not therefore encourage teachers to take context seriously (Hacker & Rowe, 1997; Hart, 2001, 2002; D. King, 2007). A questionnaire study of 11 Queensland chemistry teachers concerning their views of context based learning, found variation in what they understood by this term, that the respondents believed this approach made chemistry more relevant, but that there were constraints relating to the views of parents, other teachers and students in introducing such innovation, consistent with the views of teachers attending the ACER conference forums.

### 4.3.5 Expanding the voices that speak to school science

Fensham (2002) describes how academic scientists and science educators have traditionally been major players in the shaping of the school science curriculum and argues the need to look more widely to identify appropriate content for the contemporary science curriculum. These academics have often been resistant to reform initiatives aimed at realigning the purposes of school science. A number of Australian studies have shown the influence of university science academics in opposing changes to the school science curriculum (Forgasz, 1998; Hart, 2001, 2002). Hart’s (2001) study of an attempt to humanise the Victorian Physics curriculum showed how traditional conceptions of science held by non-science curriculum decision makers influenced curriculum innovations. Aikenhead (2006, p. 48) similarly reviews studies showing the resistance to reform of the traditional science curriculum by academic stakeholders.

Tytler and Symington (2006) ran focus groups of scientists working in Australia’s research priority areas, such as advanced materials, climate change, or preventative health care, in order to interrogate the nature of contemporary science that spoke to major societal issues. As described by Tytler (2007a):
The focus group sessions provided compelling arguments for the importance of science to the country’s future. There was a universal concern with the level of public understanding of, and response to science. The groups commonly promoted the view that citizens needed to be able to respond critically and analytically to new technologies and associated issues… With regard to the nature of science, the view that emerged for all focus groups was one of science constantly evolving, of practice in science focusing around multi-disciplinary teams, of science linked with technology, and science dealing with complex systems with many interconnected effects such as the need to balance economic, social, energy and environmental factors. The groups had a great deal to say about school science, which many participants regarded as representing an outdated and discipline-bound view of science (p. 27).

Tytler and Symington’s focus groups tended to argue for a focus on lifelong learning through engaging students’ interests and establishing a disposition towards science, rather than on knowledge accumulation aimed at future scientists. They tended to advocate the processes and skills and habits of mind of science rather than the conceptual structures. In this they were consistent with the views of community leaders in an earlier study (Symington & Tytler, 2004), who argued for an education ‘for science in life’ that would engage students at a personal level, rather than an education ‘about science’. This position is consistent with a ‘humanistic’ perspective on school science (Aikenhead et al., 2006).

The relevance of this research for the current review is that it highlights how the concern to raise participation in STEM might interact with broader questions about school science. First, there is a clear challenge here to align school science more strongly with the essence of contemporary science practice. Second, there is an acknowledgement of the wider purposes of school science, beyond the economic purpose of enlisting future STEM professionals, as important as that is. Third, there is the question as to what should be the appropriate focus of school science, in order to best prepare students who do choose to become STEM professionals. Fourth, there is the question of how best to serve Australia’s future as a scientifically and technologically advanced society, striking a balance between educating future science professionals and educating future citizens who may well engage productively with STEM at different points in their lives.

Symington and Tytler’s (2004) informants included people with no formal training in science but who ran science based industries, and made decisions on or supported science related public policy issues. Tytler, Duggan and Gott’s (Tytler, Duggan, & Gott, 2001b) study of an environmental dispute in a North England farming community demonstrated the layers of public involvement with important science policy decisions, including local farmers and residents, through to retired engineers and industrial chemists, lawyers and politicians. Their analysis of the science knowledge needed to resolve the issue (Tytler, Duggan, & Gott, 2001a) supports the contention that learning about how science deals with evidence is the key to a useful science education. They made the point that much of the science on which the dispute turned was either not known when the protagonists went to school, or was too contextual, or too complex to have been taught.
4.4 Responding to the changing nature of science and society

Tytler (2007a) called for a ‘re-imagining’ of school science, based largely on the claim that school science has failed to reflect the changing practices of science, and that its exclusive emphasis on canonical knowledge structures does not reflect the needs of a contemporary scientific profession. In a foreword to that monograph, Dr. Jim Peacock, Australia’s Chief Scientist, argued:

And how society has changed! The way in which I learned science at school does not meet the needs of today’s students. In my lifetime, scientific research has broadened from an individual-oriented approach to team-based work and collaboration with other researchers and industry. Collaborative science is essential if we are to address national impact and global problems such as climate change. A different skills set is needed in today’s scientists. We can no longer focus on a niche area. Collaboration is now the norm. We are all living in a connected world…

Science is a constantly evolving field. Thus, much of the content knowledge I learned in school and university was not directly used in my career as a plant scientist. I learned to approach individual experts in a field, tracking information in how to tackle an unknown. Every day we are faced with unfamiliar tasks and required to make decisions in unfamiliar contexts. Students will become more effective citizens by being able to locate, analyse and critique information to form their own opinions rather than being able to provide the atomic number of an element such as lead. (pp iii-iv)

Scientific knowledge and scientific practice are influenced by social, cultural and technological change, which have repercussions for school science, and also for the image of science held in the community. Some of these changes and possible responses, summarised from Tytler (2007a), are detailed below.

4.4.1 The changing nature of science and public engagement with science

The increasingly technological nature of contemporary society, and the increasing need to manage resources and the effects of development carefully, place new imperatives on scientific knowledge, and community literacy with scientific concepts. The practice of scientific research and technological development has changed substantially over the last 50 years towards the interdisciplinary and collaborative environment described by Dr. Peacock. Science is now ‘big business’ and, as argued by focus group scientists in the Tytler and Symington (2006) study, engaged with large social and ethical issues. The skills needed by research scientists include creativity, personal interest, perseverance and willingness to inquire (Fensham, 2004), as well as knowledge (which soon becomes outdated). Science education has an increasingly important role to play in preparing future citizens to engage with an increasing range of personal and public science-based issues.

Public challenges to science, from a number of directions, have gained much air space in recent decades, and demand response in science education. These include postmodernist, feminist and post colonial critiques of Science’s claim to high status knowledge, questions about the nature of science and its cultural antecedents, which have not traditionally recognised the need to accommodate
indigenous perspectives (Aikenhead, 2001a), challenges from religious perspectives such as with the evolution/creation debate, or questions of the perceived lack of values in science, concerns about public perceptions of the vested interests of science and scientists, and seemingly increasing non rationalist beliefs amongst youth.

There has been a steady stream of initiatives, which seek to change attitudes to STEM education and careers. These range from improving students’ and their parents’ knowledge of STEM related careers to attempts to change the image of science and mathematics in the wider community. Munro and Elsom (2000) recommended, following research into student choice of science at age 16, a national campaign to help parents understand the broader values of science subjects as important aspects of education. The British Government is currently launching an advertising campaign aimed at encouraging young people in the early years of secondary school to consider persisting with STEM education and careers. The approach, using the slogan: Look what science can do for you, uses the underlying metaphor of the pathway. It will be interesting to observe the success of this and similar programs.

4.4.2 The resilience of traditional school science

The societal changes outlined above have profound implications for science education. Although many changes have been made to school science over the last 50 years, and many contestations that have led to reforms, school science has maintained its emphasis on the distinctive knowledge structures of science, and continued to emphasise practical work illustrating concepts and techniques. This basic shape has been supported by assessment regimes that have remained remarkably stable over all this time.

This review must concern itself with the questions – to what extent does the need to attract students into STEM pathways imply a challenge to this traditional shape of science education, and if it does, which forces uphold the status quo, and must be challenged?

There have been many attempts to widen the school science curriculum, for instance to place greater emphasis on inquiry, on the nature of science, on its contemporary practices, or on the cultural and the human aspects of science. They have not generally been successful in challenging the disciplinary status quo. Part of the reason for the persistence of conventional science relates to the strong discursive traditions subscribed to by teachers of science resulting from their enculturation during their own schooling and undergraduate studies (see Aikenhead et al., 2006, p. 64, for a discussion of teacher identity and allegiance). This culture is strongly represented in school science practices, supported by resources such as textbooks, laboratories and their associated equipment, timetabling arrangements and by assessment and reporting traditions. Further, teachers over the years develop effective ways of delivering canonical content, and many may lack the knowledge, skills and perspectives required for teaching that challenges science conventions and effectively expands its range of purposes and practices. Teachers of science are very much a community of practice with their own standards, values
and cultural norms, and largely maintain a view of their practice as a process of information transmission. As such, reform is a difficult process.

There are real choices that need to be made in reforming the teaching of science. Osborne (2006) describes the paradox that teaching the best that science has to offer, for the future scientist, inevitably involves it being seen as ‘received knowledge’ and thus not open to questioning. This misrepresents the nature of science as it is actually experienced by the expert practitioner, yet is a tradition that is based on an appreciation of the achievements of science. The dilemma, then, is how we might juxtapose the need to teach established scientific knowledge, with the need to represent science as it is practised in contemporary settings. Davies (2006), describing the curriculum of the Australian Science and Mathematics School (ASMS), emphasised the links between teachers, students and practising scientists. In the ASMS, science is made contemporary by contact with practitioners, by selection of socially relevant, interdisciplinary topics, and by ‘weaving scientific understanding and logic into cultural, social, historical, legal and ethical perspectives’ (p. 57). Further examples of this approach, of linking school science with contemporary practice through partnerships, will be described in a later section of this review.

At the current time, there is gathering support for change to school science curriculum. Academic scientists have long been the gatekeepers of the traditional structures of school science, but given the falling enrolments, and looming lack of STEM professionals, there is an increasing willingness and impetus to support change, and recognise the gap between classroom, and contemporary science practice. Dr. Peacock’s views, described above, are a good example of this willingness. Any call for change to the science curriculum and teacher practice will need the support of professional scientific bodies.

### 4.5 Student engagement with science

#### 4.5.1 Determinants of student attitudes to science

In heeding the calls for change, described above, we need to be clear about the nature of students’ responses to science as it is currently taught, and the factors that determine engagement. The research evidence would suggest that after gender, the major factor determining student engagement with science is the quality of their experience in the classroom. As to the exact nature of the experience, the data paint a mixed picture. For instance, the Research Council’s UK survey of public attitudes to science asked people whether they thought their school science was worse than other subjects, about the same, or better. One in 5 young people (age 16-24) thought it worse but 1 in 3 thought it better. Likewise a study conducted in England (Jenkins & Nelson, 2005) for the Relevance of Science Education project (ROSE) found, using a sample of 1277 students from 34 schools that 61% agreed with the proposition that school science is interesting.
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The ROSE study is an international project led by a Norwegian academic and science educator, Svein Sjøberg. Using an extended questionnaire, it has surveyed the attitudes of young people (age 15-16) towards school science in over 20 countries. Figure 4.2 shows one of the major findings of the study – students’ response to the item ‘I like school science better than other subjects’.

Figure 4.2: Data from the ROSE study showing students’ responses to the question ‘I like school science better than most other school subjects’. Percentage answering Agree plus Strongly agree, by gender.

The increasingly negative response the more developed the society is a prominent feature suggesting that the issue of student engagement with school science is a deeply cultural phenomenon and a reflection of the values and identity of contemporary youth. Indeed, there is a 0.92 negative correlation between responses to this item and the UN Index of Human Development (Schreiner & Sjøberg, 2007).

The data obtained from the interview and focus group studies described in the previous section (Lyons, 2006a) offer some insights into the nature of the problem. Young people’s dissatisfaction were found to be a response to an overly transmissive pedagogy, where there was little time to discuss or explore ideas, an over-reliance on copying or un-engaging writing activities, and a common perception that science was a difficult subject. In addition, much of the content of school science was seen by students to be divorced from their daily lives and lacked relevance. The latter sentiment is best captured by the following quotation:
The blast furnace, so when are you going to use a blast furnace? I mean, why do you need to know about it? You’re not going to come across it ever. I mean look at the technology today, we’ve gone onto cloning, I mean it’s a bit away off from the blast furnace now, so why do you need to know it? (J. Osborne & Collins, 2001)

Whilst a good argument can be made for teaching about the process that is used to produce one of the major materials on which societies depend, the point here is that the argument had not been made, or was not apparent to this young man. School science draws a strong line between science and technology, with the science taught first and then – if there is time – the applications. The emphasis on a body of well-established knowledge means that the subject can appear to have a retrospective quality consisting of the stepping stones that led us to where we are today. In contrast, young people, like the public, do not differentiate between science and technology. Asked to name the most important scientific discoveries of the 20th century, their response (in 1994) were computers, television, the phone – all of which are technological artifacts. Moreover, the vision of young people is prospective – what is more likely to excite them is the challenges to which they can contribute – a vision which school science does little to meet.

However, there is considerable evidence to suggest that changes to the curriculum are unlikely to make a significant difference to student uptake (Aikenhead, 2005). For instance, a recent evaluation of a new and innovative course now taken by approximately a third of all students in England, age 14-16, demonstrated that the course only led to a marginal increase in the number of students who said they would be more likely to study science post-16 (Ratcliffe, Hanley, & Osborne, 2007). This may partly reflect the possibility that students’ experience before age 14 is a significant determinant of their choice to pursue, or not, the study of science. This is not to argue that there are not other rationales for improving the curriculum but rather that any policy of implementing curriculum changes may have limited impact on student uptake of science.

### 4.5.2 The influence of teachers and school resources

A now considerable body of evidence exists that identifies the quality of teaching as a major determinant of student engagement with and success in a school subject (Barber & Mourshed, 2007; Cooper & McIntyre, 1996; Darling-Hammond, 2000, 2007; Maltese & Tai, 2008; J. Osborne, Simon, & Collins, 2003; Rivkin et al., 2005; Rowe, 2004; Sanders, Wright, & Horn, 1997; Strauss & Sawyer, 1986; Wayne & Youngs, 2003; Woolnough, 1994). The most recent and perhaps systematic study is that undertaken in two states in the USA by Darling-Hammond (2007), who shows that the major factor correlating with the percentage of students scoring ‘below basic’ on the South Carolina state tests are the percentage of teachers on substandard certificates and the percentage of vacancies open for more than 9 weeks. In contrast, teachers with advanced degrees correlate negatively. Likewise in the state of Massachusetts the two factors correlating most highly with the number of students failing the State English language test were the percentage of teachers unlicensed in the field and the percentage
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of paraprofessionals not highly qualified. A major OECD commissioned international review of school systems (Barber & Moushed, 2007) found:

The experiences of these top school systems suggests that three things matter most: 1) getting the right people to become teachers, 2) developing them into effective instructors and, 3) ensuring that the system is able to deliver the best possible instructions for each child (p. 5)

Barber and Moushed argued on the basis of comparative data across systems, relating to student outcomes, that reform efforts are often ineffective in delivering student learning and engagement if they do not reach down into classroom instruction, where the real effects on learning take place.

The quality of the educational experience provided by teachers - the learning and teaching methods used – play a critical role in students’ success in and take up of STEM. Good quality teachers are more important than any other factor (Barber & Moushed, 2007; Darling-Hammond, 2007; Druva & Anderson, 1983; Haladyna & Shaughnessy, 1982; Myers & Fouts, 1992). A significant body of research evidence suggests that tailoring teaching style and pedagogies to suit students’ learning needs is an effective way to increase attainment levels and engagement. Hattie & Timperley (2007) found that interventions involving feedback are more effective than any other educational intervention, whilst Williams (2007) calculates that, for the achieved effect size, the cost of formative assessment is lower in comparison to any other educational intervention.

Ensuring that mathematics and science classes are taught by qualified and capable teachers should thus be a major aim of any intervention to improve STEM retention. The recent PISA report gives some data on the human resource problem of recruiting and filling science posts and some comparable countries are included in Figure 4.3 (OECD, 2007b).

The data from Figure 4.3 would suggest that the supply in Australia of suitably qualified science teachers is worse than the OECD average in that there are comparatively fewer students in schools where there is no requirement to fill a teaching post, and there is some concern about the quality of teachers recruited to ‘hard to fill’ positions. Australian schools are better than the OECD in filling vacant posts. These data would also suggest that Finland’s success in OECD measurements of student performance is, at least in part, due to a very stable teaching force. The policy implication of this is fairly clear – there is a need for Australia to invest significantly in the human resource that it has for the teaching of science – both in their recruitment and retention. This need has been recognized by Australian policy documents, and ways need to be found to make it happen.
Figure 4.3: School principals’ reports on vacant science teaching positions and their perceptions of the supply of qualified science teachers

### Percentage of students in schools where the principal reported

<table>
<thead>
<tr>
<th>Country</th>
<th>No Vacant science teaching positions needing to be filled</th>
<th>All vacant science teaching positions filled</th>
<th>No vacant science teaching positions or all vacant science teaching positions filled but where a lack of qualified science teachers hinders instruction to some extent or a lot</th>
<th>One or more vacant science teaching positions filled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>22</td>
<td>75</td>
<td>29</td>
<td>4</td>
</tr>
<tr>
<td>UK</td>
<td>19</td>
<td>73</td>
<td>11.1</td>
<td>9</td>
</tr>
<tr>
<td>New Zealand</td>
<td>19</td>
<td>79</td>
<td>15</td>
<td>1.5</td>
</tr>
<tr>
<td>Unites States</td>
<td>26</td>
<td>71</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>Finland</td>
<td>60</td>
<td>37</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>OECD Average</td>
<td>38</td>
<td>59</td>
<td>18</td>
<td>4</td>
</tr>
</tbody>
</table>

When it comes to student teacher ratios, the PISA data gives a figure for Australia of 13.4, which compares favourably with the UK (15.3), the USA (15.3), negatively with countries such as Finland (11.3) and Greece (8.9), but matches the OECD average.

Australia seems to be well placed on other measures. Principals were surveyed on their perceptions of a range of factors related to science, including access to resources of various kinds. A composite index was produced which showed that few principals in Australia (in common with those in Switzerland and Japan) perceived a shortage of resources to be hindering the capacity of their schools to provide appropriate instruction.

There are many activities external to the classroom which can promote students’ learning of science help to motivate and stimulate student interest. These activities include going on excursions, participating in science competitions, and science fairs, engaging in extracurricular science projects, and belonging to a science-related club. The prevalence of these activities, as reported by school principals, was summarized by PISA in an index which ranges from +2.5 to -2.5. Some countries are
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well below the OECD average such as Japan (-1.16), Denmark (-0.83), Iceland (-0.71), Finland (-0.60) and the Netherlands (-0.51). Others are above such as the Slovak Republic (0.70) and Portugal (0.66) and New Zealand (0.51). Australia too is above on this index with a value of 0.41

The analysis of PISA used a multi-level model to look at how much of the variance in student performance in science could be explained by human and material resources and other factors after adjusting for socio-economic and demographic factors. These were:

• School principals’ reports regarding the practice of ability grouping for all subjects within schools (students in schools using ability grouping for all subjects within schools scored 4.5 points lower than students in school using no ability grouping or ability grouping only for some subjects, all other things being equal).

• School principals’ reports regarding high academic selectivity of school admittance (students in schools in which academic records or feeder school recommendations were a prerequisite for school admittance score 14.4 points higher than students in schools applying a moderate selective admittance policy, all other things being equal).

• School principals’ reports regarding whether the school’s achievement data are posted publicly (students in schools posting achievement data publicly score 3.5 points higher compared with students in schools not posting achievement data publicly, all other things being equal).

• School principals’ reports regarding the school average time students invest in learning for science, mathematics and language at school (students in schools with one additional average hour per week score 8.8 points higher, all other things being equal), and self-study (students in schools with one additional average hour per week score 3.1 points higher, all other things being equal).

• School principals’ reports regarding school activities to promote students’ learning of science (one additional unit of this index is equivalent to an advantage of 2.9 score points in student performance, all other things being equal).

• Education systems where schools have a higher degree of autonomy in budgeting (students in education systems where schools with one additional standard deviation on the index of autonomy in budgeting score 25.7 points higher, all things being equal).

Clearly the last factor has the most major influence. In Australia 71% of school principals stated that they had responsibility for formulating the school budget and 93% the budget allocations within schools. These figures are better than the OECD average of 57% and 84% respectively suggesting there is little room for improvement here. However, the other factors do give some evidence of where policy initiative might help to improve student attainment. Indeed, the PISA report suggests that one quarter of the variation in student performance both between and within countries can be explained by these factors.
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Nevertheless, two caveats must be given in acting on this data. The first is that these findings only point to those factors which influence student attainment not student attitudes towards school science. The evidence about the relationship between these two concerns is mixed. Whilst the review conducted by Osborne et al. (2003) found that the two were only weakly correlated, the recent PISA survey found that there was a strong association between the general valuing of science and student attainment. Part of the answer might lie in what is being measured by such an attitude construct – students might value science whilst still feeling that it is of little interest to them personally (J. Osborne et al., 2003). The second is that it is not clear to what extent these factors are causally related. That is, are schools which control their own budgets able to employ better qualified teachers and do better qualified teachers stay longer in schools and go out of their way to run science clubs and provide a range of science activities outside the classroom?

4.5.3 Young people’s attitude to science

The research indicates that students’ attitudes towards school science decline from their early years onward (Ormerod & Duckworth, 1975; J. Osborne et al., 2003; Pell & Jarvis, 2001; Piburn, 1993). This was discussed in relation to Australian data in the previous section. By itself this is unsurprising as student attitudes to all school subjects decline overall during this period (Whitfield, 1980). There is however data that suggests student attitudes to school science are relatively positive. Jenkins and Nelson found that 61% of a sample of 1277 English students, age 15, responded with either low agreement or agreement to the statement ‘school science is interesting’ and, likewise, 61% thought that the science that they learnt in school would help them with their everyday life. 31% also thought that they liked school science better than other subjects which is reasonable given the diversity of subjects on offer. This finding also matches that from the 2008 survey of the public attitude towards science, conducted by the Research Councils UK, which showed that 34% of 16 to 24 year olds thought that school science was ‘better than other subjects’.

The ‘problem’ as seen by a range of influential reports in the UK, the USA, and the EU is student interest in pursuing a scientific career or the further study of science (COSEPUP, 2005; European Commission, 2004; Lord Sainsbury of Turville, 2007; Roberts, 2002). Jenkins and Nelson found that only 21% of their sample had either low agreement or agreement with the statement ‘I would like to become a scientist’. Likewise, the PISA survey of 2006 revealed similar, but slightly less negative attitudes in Australian youth (Figure 4.4) (OECD, 2007b).
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Figure 4.4: Percentage of students agreeing or strongly agreeing with the following statements

<table>
<thead>
<tr>
<th>Country</th>
<th>Australia</th>
<th>UK</th>
<th>USA</th>
<th>Average (All Countries)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would like to work in a career involving science</td>
<td>39</td>
<td>34</td>
<td>45</td>
<td>37</td>
</tr>
<tr>
<td>I would like to study science after secondary school</td>
<td>34</td>
<td>33</td>
<td>45</td>
<td>31</td>
</tr>
<tr>
<td>I would like to spend my life doing advanced science</td>
<td>15</td>
<td>13</td>
<td>24</td>
<td>21</td>
</tr>
</tbody>
</table>

The conclusion to be drawn from this is that interest in a scientific career is a minority interest but, nevertheless, a healthy minority.

The PISA survey measured students’ interest in learning the science topics they were being tested on. The composite score for Australia was 465 with no significant difference between subjects whilst the OECD average was 500. The survey also measured the extent to which students agreed with statements about the value of scientific enquiry such as ‘the systematic study of fossils is important’. Here Australian students scored 487 with little gender difference where the average was again 500. These data would suggest that Australian students have a more negative attitude than the average OECD country.

Other attitude constructs were also measured. In Figure 4.5, the scales are normalised so that scores can vary between -1 (negative) to +1 (positive) with the average value 0.

What this data in Figure 4.5 suggest is that Australian students have a below average interest in learning science. They clearly do not spend much of their spare time on science-related activities. The one positive element is that they are interested in learning science for its instrumental value for future careers but, sadly, not for its intrinsic interest. The major difference between girls and boys is that boys would appear to have more belief in their capabilities and competence but this is not matched by an enhanced interest in science. What it also shows is that enjoyment of science and interest are both below average.
**Figure 4.5**: Selected results from the 2006 PISA study of Australian students’ attitudes towards science.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Overall Value</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Value of Science (on a scale of -1 (negative) to +1 (positive))</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Value of Science</td>
<td>-0.10</td>
<td>0.00</td>
<td>-0.11</td>
</tr>
<tr>
<td>Self-Efficacy</td>
<td>0.12</td>
<td>0.19</td>
<td>0.04</td>
</tr>
<tr>
<td>Self-Concept (belief in one’s own academic competence)</td>
<td>-0.03</td>
<td>0.07</td>
<td>-0.14</td>
</tr>
<tr>
<td>General Interest in Science</td>
<td>-0.22</td>
<td>-0.23</td>
<td>-0.21</td>
</tr>
<tr>
<td>Personal Value of Science</td>
<td>0.02</td>
<td>0.06</td>
<td>-0.04</td>
</tr>
<tr>
<td>Instrumental Motivation to Learn Science</td>
<td>0.11</td>
<td>0.11</td>
<td>0.10</td>
</tr>
<tr>
<td>Enjoyment of Science</td>
<td>-0.08</td>
<td>-0.03</td>
<td>-0.12</td>
</tr>
<tr>
<td>Science Related Activities undertaken in spare time</td>
<td>-0.29</td>
<td>-0.20</td>
<td>-0.39</td>
</tr>
<tr>
<td>Future-orientated motivation to learn science</td>
<td>-0.07</td>
<td>-0.03</td>
<td>-0.12</td>
</tr>
</tbody>
</table>

Nevertheless, the following figure shows that Australian students match the OECD average for students’ expectation to do well at science, and the number expecting a science-related career are slightly above average.

**Figure 4.6**: Results from the 2006 PISA study showing aspects of students’ attitudes towards science and science-related careers.

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Males</th>
<th>Females</th>
<th>OECD average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doing Well at Science Matters</td>
<td>72%</td>
<td>71%</td>
<td>73%</td>
<td>73%</td>
</tr>
<tr>
<td>Students Expecting a science-related career</td>
<td>28%</td>
<td>27%</td>
<td>29%</td>
<td>25%</td>
</tr>
</tbody>
</table>

The PISA study also gathered data on student attitudes to environmental issues (Figure 4.7), using a normalised scale on which scores can vary between -1 (negative) to +1 (positive) with the average value 0.
Figure 4.7: Selected findings of Australian students’ attitudes towards environmental issues from the 2006 PISA study.

<table>
<thead>
<tr>
<th>Environmental Issues</th>
<th>Overall Value</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awareness of Environmental Issues</td>
<td>0.10</td>
<td>0.19</td>
<td>0.01</td>
</tr>
<tr>
<td>Concern for Environmental Issues</td>
<td>-0.19</td>
<td>-0.29</td>
<td>-0.07</td>
</tr>
<tr>
<td>Students Optimism about environmental issues</td>
<td>-0.13</td>
<td>-0.03</td>
<td>-0.24</td>
</tr>
<tr>
<td>Students sense of responsibility for environmental issues</td>
<td>-0.25</td>
<td>-0.34</td>
<td>-0.16</td>
</tr>
</tbody>
</table>

This data suggests that Australian students have a greater awareness of environmental issues than students in most OECD countries but are relatively untroubled by them and they do not see it as their responsibility to act — data that would suggest they have a lack of concern for the broader society.

4.5.4 Accounting for these findings – identity in late modern society

Several pieces of research have helped to contribute to an understanding of how youth respond to science, school science and environmental issues (Costa, 1995; Haste, 2004; Schreiner, 2006). Two studies are illuminating here. Haste conducted a survey of the values and beliefs that 704 eleven to twenty-one year old UK individuals held about science and technology. She found that there were four groups of students:

- The ‘Green’ who held a set of ethical concerns about the environment and who were sceptical about interfering with nature. Members of this group were predominantly girls under 16 who would be interested in a job related to science.
- The ‘Techno-investor’ who was enthusiastic about investing in technology and the beneficial effect of science. Such individuals trusted both scientists and government and consisted of boys under 16 and young men over sixteen in the workforce.
- The ‘Science Orientated’ who were interested in science and who held a belief that a ‘scientific way of thinking’ can be applied widely. This group was predominantly boys over sixteen both in full-time education and in the workforce.
- The ‘Alienated from Science’ who found science boring and were sceptical of its potential. The group consisted predominantly of younger girls and young women over sixteen in the workforce who were not interested in a job related to science.

Haste found that girls were not less interested in science or science careers than boys, but focused on different things. They related more strongly to ‘green’ values associated with science (socially
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responsible and people-oriented aspects of science) than to the ‘space and hardware’ aspects which often dominate communication about science. She argues that the science curriculum needs to represent both these dimensions of science, and to acknowledge the value aspects and ethical concerns surrounding science and its applications.

Schreiner’s study, conducted in Norway, administered a questionnaire which had been extensively validated to a sample of 1204 students drawn from 53 randomly selected schools consisting of equal numbers of boys and girls. From a cluster analysis of her sample, she identified 5 distinct student types which she calls:

- The Selective Boy which as its name implies was predominantly but not totally male. He has clear ideas about who he is and shows his identity by expressing very high interest in stereotypical masculine topics. School science is interesting and not difficult but not as interesting as other subjects. Working with people is not important for him.
- The Selective Girl which was predominantly but not totally female. This student is modern, reasonable, outspoken and self-expressive. She knows who she wants to be and who she does not want to be. School science is somewhat difficult, and not very interesting and she prefers other subjects much more. The topics she is interested in learning about are predominantly concerned with the human body and health.
- The Reluctant which consists of 37% girls. These students are aloof and unwilling and make clear to their peers that science is not their kind of stuff. They are not interested in learning about anything much in science; do not see the benefit of science to society and, in general, do not plan for a job that requires an advanced education.
- The Undecided which consists of 40% girls. These students are not disinterested but there is not much interest either. Schreiner argues that this type of student is more or less invisible. These students do, however, prioritise environmental protection for society.
- The Enthusiast which consists of 53% girls who find school science interesting, useful and not too difficult but science classes are not more interesting than other subjects. These are the school-committed student types; they like science and school and appreciate the value of education and school.

Whilst the samples used in these studies are different, both in their age and country, and the factor analysis produced slightly different results, there are clear similarities, which suggest that interest in science is highly gender specific. All of the groups in the Schreiner study, bar the ‘Reluctant’, do, however, rank their response to the question ‘school science is interesting’ positively.

In the Schreiner survey there were 17 items exploring what students considered important in any future job that were reduced to 6 composite variables. Four of these were:

- ‘Realise and develop yourself’ which all groups considered very important though the ‘Reluctant’ less so.
- ‘Using hands and tools’ which all bar the selective boy responded negatively to and the selective girl very negatively.
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- ‘Work with and help people’ which was important to the selective girl and enthusiast but unimportant for the reluctant and the selective boy.
- ‘Reach power and glory’ which was unimportant to all groups though marginally more important for the selective boy.

Mean rankings for the responses to the stimulus item ‘school science has opened my eyes to new and exciting jobs’ on a scale of 1 (Disagree) to 4 (Agree) are shown in Figure 4.8.

**Figure 4.8:** Mean responses to the stimulus item ‘school science has opened my eyes to new and exciting jobs’

<table>
<thead>
<tr>
<th>Cluster</th>
<th>School science has opened my eyes to new and exciting jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selective Boy</td>
<td>2.05</td>
</tr>
<tr>
<td>Reluctant</td>
<td>1.53</td>
</tr>
<tr>
<td>Undecided</td>
<td>2.13</td>
</tr>
<tr>
<td>Enthusiast</td>
<td>2.48</td>
</tr>
<tr>
<td>Selective Girl</td>
<td>1.63</td>
</tr>
<tr>
<td>Total</td>
<td>1.94</td>
</tr>
</tbody>
</table>

Given that the mean on this scale is 2.5, all of these rankings were negative. Perhaps of most interest though is the composite variable – ‘future science studies and job’ which shows the responses to 4 items10 for which the mean rankings are shown in Figure 4.9, and which were also negative.

**Figure 4.9:** Mean Responses to the composite variable ‘future science studies and job’ by different groups.

10 a. School science has opened my eyes to new and exciting jobs
b. I like school science better than most other subjects
c. I would like to become a scientist
d. I would like to have as much science as possible at school
Moreover, Schreiner points to the fact that students’ response to the item ‘I like school science better than most other subjects’ correlates most strongly with three of the factors in this composite variable. This she sees as supporting the hypothesis that when young people choose their educational trajectory, it is their personal interest that has a major influence on their decision. If so, it is a matter of concern that the PISA data (Figure 4.5) show that Australian students’ interest in science is low. Hence, the clear question that emerges as a corollary is ‘what generates student interest in a subject?’ The findings of this review would suggests that, after gender, it is the quality of teaching.

What conclusions can be drawn from these analyses for science education? Here the work of Schreiner provides some useful insights. Arguing from a sociological perspective, she suggests that contemporary society gives pre-eminence to the individual. Drawing on the work of Beck and Beck-Gernsheim, she argues that there is little point in re-vitalising yesterday’s concepts such as obedience, conscientiousness and humility as the processes of individualisation at work in our society have already shaped the values of modern youth (Beck & Beck-Gernsheim, 2002). Such concepts were part of the grand narratives and traditions that shaped societies – many of which have been weakened in an era of late modernity by the dissolution of family and the increasingly reflexive nature of society (Giddens, 1990). Rather, there is a need to appeal to present solutions to the major problems facing the world in terms of the unique and prestigious contribution of the individual. In short, what engages modern youth is not the stepping stones by which we arrived at this point in history but rather their potential individual contribution to the future.

Late modern societies have been characterised by Inglehart (1990) as post-materialistic societies. That is not to say that material goods are not valued but their purchase is often not the product of necessity but rather a reflection of one’s identity. The values emphasised by such societies are care for the environment, democracy, care for others, creativity and self-realisation. That this is so is reflected in the fact that recruitment in Western societies into medicine, the life sciences and environmental studies is not falling and, in these areas, girls often outnumber boys. (This argument, however, does not fit well with the PISA data for Australian students). In this context, education is continuously evaluated against how it contributes to a student’s self-development asking ‘what does it mean for me?’ The desire, therefore, to work in an area that students find meaningful is a driving force in their choice of subjects to study. Meaning is reflected in the valuing of activities that offer the potential for self-realisation; creativity and innovation, working with people and helping others; and/or earning lots of money. The problem for school science is that it is associated with building bridges, making chemicals, ever smaller mobile phones, and faster computers – very few of which comprise the values listed above. Rather school science needs to offer a vision which shows that it is the physicist or engineer who is
going to make the major contribution to providing alternative energy sources, animal- and environmentally-friendly food production, new methods of eliminating disease, and solving the challenge of global warming. In short, what is needed is a transformation of the vision offered by school science – in essence a cultural and societal transformation that recognises the value of science and explains why science matters. Students need to see that the work of the scientist and engineer is at the centre of solving humanities problems and involves working with people. As Schreiner (2006, p. 269) argues – it is “important that school science (and schooling in general) aim to develop in young people a feeling that they can influence the development at a personal as well as at a wider local, national and even global level.”
5 Making sense of student pathways

5.1 Choice and Identity

5.1.1 Point of choice, and pathways

Recent research evidence – all published in the last three years – strongly supports the idea that the majority of children are making up their minds about whether to follow a STEM related career before the age of 14. In a recent analysis of data collected for the US National Educational Longitudinal Study (NELS), Tai et al. (2006) looked at what a sample of 3,359 students said about their age 30 career expectations at age 14 and then compared it with the subject of their earned degrees. Their finding was that by age 14 students with expectations of science-related careers were 3.4 times more likely to earn a physical science and engineering degree than students without similar expectations. This effect was even more pronounced for those who demonstrated high ability in mathematics – 51% being likely to undertake a STEM related degree. Indeed Tai et al.’s analysis shows that even the average mathematics achiever at age 14 with a science-related career aspiration has a greater chance of achieving a physical science/engineering degree than a high mathematics achiever with a non-science career aspiration (34% compared to 19%). The importance of this study lies as much in its methodology – the use of longitudinal data gathered at two points 10 years apart – as in its finding.

Further evidence that children’s experiences prior to 14 are the major determinant of the decision to pursue the study of science comes from a survey by the Royal Society of 1141 scientists, engineers and technologists regarding the pursuit of scientific careers (Royal Society, 2006). A major finding was that just over a quarter of respondents (28%) first started thinking about a career in STEM before the age of 11 and a further third (35%) between the ages of 12 -14. Female participants generally reported a first interest in science a few years later than males.

Two more recent studies of contemporary youth support this analysis. A study conducted for the Engineering Council in the UK of factors influencing subject/career choices at age 14 found that more than three-quarters (79%) of the students surveyed claimed that they already had an interest in working in a specific job or career area and more than two-thirds (72%) of those reported that their choices were suitable for their area of work (ETB, 2005a). Students in the survey were also asked about their reasons for choosing optional courses. The three main reasons were ‘interest in subject or enjoy subject’ (91%); ‘need subject for future career/job/training’ (87%); and ‘good at subject’ (79%). No other reason was given by more than 35% of the sample. Further analysis showed these trends to be even more marked for students of higher ability. Likewise, a recent small-scale longitudinal study conducted by Lindahl (2007) following 70 Swedish students from Grade 5 (age 12) to Grade 9 (age 16) found that their career aspirations and interest in science was largely formed by age 13. Lindahl concluded that engaging older children in science would become progressively harder. One caveat that should be
applied to this and other findings is that they do not necessarily imply that student choice is a conscious process. Rather, what they suggest is that it is early experiences before the age of 14 that are framing student dispositions towards the future study of science. Sfard and Prussak’s (2005) research into how migrant students in Israel built strong identities linked to the narratives they told about themselves and others fits with these findings. These students had more idea about their future directions for mathematics learning than those students born and brought up in Israel.

The policy implications of these findings are quite clear – that the priority for expenditure on initiatives to interest young people in school science should be given to those working with young people of age 14 or under. After that, gaining young people’s interest in the study of science and mathematics becomes progressively harder as initiatives are addressing a diminished audience.

Maltese and Tai (2008) interviewed 116 scientists and graduate students in science concerning issues related to their transition from student to scientist. They used the nVivo software analysis tool and a grounded theory, constant comparison method to identify main themes coming from these interviews. A major finding was that 65% of the respondents reported early interest in science (prior to middle school), 30% reported their interest began in middle or high school, and only 5% claimed they did not find science interesting until their college years. There was no difference by gender in the number expressing early interest, but a significant difference by field (81% of physicists claimed early interest compared to 54% of chemists). There were gender differences in the responses, as shown in Figure 5.1 below, with females claiming school related interest most influential, and males claiming intrinsic interest.

\textit{Figure 5.1: Sources of interest in science for scientists and graduate students in science}

\begin{table}[h]
\centering
\begin{tabular}{lll}
\hline
\textbf{Source of interest} & \textbf{Female} & \textbf{Male} \\
\hline
School related interest (content, lab experiments, projects or enrichment experiences, teacher encouragement of teaching style, performance success) & 52 & 33 \\
Self related or intrinsic interest (tinkering, reading science, conducting home experiments) & 24 & 57 \\
Family related interests (growing up in families were science permeated many activities, or parental pressure to pursue science) & 24 & 10 \\
\hline
\end{tabular}
\end{table}

Maltese and Tai found that encouragement played a major role in sparking initial interest for males as well as females, with respondents referring to teacher likeability, engaging mannerisms, and personal encouragement. They note that ‘the way teachers interacted with students, rather than their content knowledge, was an important factor in getting students interested in science’ (p. 19), and argue two points from their data:
• intervention programs aimed at the middle or high school are likely too late, given that interest is established largely before this; and

• improvement in science education should not be limited to training teachers with a view to increasing understanding of scientific principles — the more important factors for getting students to consider careers in science include providing an engaging and supportive classroom environment, and a variety of content. This concurs with the findings of Darby (2005, 2008a)

Cleaves (2005) conducted interviews with 72 high achieving secondary students, to explore the factors influencing their subject choices across time, from Year 9 to Year 11. She used a grounded theory approach to separate student trajectories into five categories that represented different patterns of choice regarding persistence, or not, in STEM: directed (students with an early and specific career goal), partially resolved (a less focused idea of career), funneling identifier (narrowing of ideas over time), multiple projector (constantly changing) and precipitating (little focus, uncommitted).

Interestingly, many of the students planning to continue study in the STEM fields reported not enjoying secondary school science. Students often reported being bored, not having a good sense of the career options in science fields, or simply enjoying other classes more. However, because they had formed a vision of the career they wanted, or understood the flexibility that study in STEM would give them, these students planned to continue in STEM. The students who did not plan to continue in STEM reported similar educational experiences, but for this group, the experiences were strong enough to deter them from wanting to continue studying science and math at an advanced level. Cleaves found parental influence and advice to be a significant factor in a number of her students’ choice, contradicting earlier research of George (2000), but she speculates that this factor may be more operative for high achieving students. Her interviews confirmed earlier studies concerning:

• disenchantment with the school science curriculum (e.g. J. Osborne & Collins, 2001);

• students with an early interest in science eliminated the STEM option because of disenchantment (similar to the findings of Lindahl, 2003);

• off-putting, stereotypical views of scientists and science (Furlong & Biggart, 1999);

• lack of appreciation of the scope of STEM work (D. Hill & Wheeler, 1991);

• the irrelevance of the science curriculum, and in particular, perceptions that it was limited to preparing students for a university research career in science (DeHart, 1998); and

• the self-perception of high achieving girls in the sample that they lacked talent in science, despite evidence to the contrary from their marks (Lindahl, 2003).

Cleaves paints a picture of interested students choosing to continue in STEM study despite negative experiences of school science, and of interested students who gain a deeper appreciation of what a
science career might look like outside of the classroom. She argues that raising the profile of science and understandings of science related work, are important in encouraging students into science. She adopts an identity framework to interpret the self-perceptions of students, showing that students’ perceptions of their ability, in conjunction with their life aspirations, drives the decision to opt into, or out of, STEM (see also Leonardi, Syngellitou, & Kiosseoglou, 1998). Sfard and Prussak’s (2005) work on narrative strengthening student identity and the resulting mathematical persistence fits with this.

Cleaves refers to the complexity of the decision pathways in her study, and warns against tendencies to recommend changes to science education curricula based only on trends in students’ perceptions of school science. The patterns of choice and student aspirations are related to science and school science in complex ways, and engagement will unlikely increase significantly simply by changing curriculum content.

Malteze (2008), in researching the factors influencing student participation in the STEM pipeline across the middle years of schooling to college degree completion, undertook a substantial analysis of a large US data set, the National Educational Longitudinal Study (NELS: 88). NELS: 88 was designed as a longitudinal study collecting data from 8th grade students in 1988, with follow up surveys in 10th and then 12th grade (1992), and again in 1994 and 2000, twelve years later.

Data collected from the students included information regarding demographics, social relationships, and academic characteristics. Students also completed achievement testing in four major academic areas including: reading, math, science, and social studies. Parent surveys gathered information on family characteristics, home environment and general academic support for the students (Malteze, 2008). Other information was also collected from teachers and parents, but this was not included in the analysis.

Malteze subjected the data to a logistic regression analysis, building the regression model in chronological blocks to allow different variables to emerge as important at each phase. The major findings include:

- There is a flow of students into and out of the STEM pipeline at various points. One of the biggest ‘leaks’ occurs when high school students make plans for their college major, rather than at the end of general college coursework in STEM.

- Student interest and ratings of their abilities in mathematics and science played a significant and positive role in each model. Students who in 8th grade indicated an interest in a science career and those who believed science would be useful for their future were more likely to earn degrees in STEM (consistent with Simpkins, Davis-Kean, & Eccles, 2006)

- A much larger group of students than those early committers, who did not indicate an interest in STEM in 8th grade, moved into the pipeline during high school and eventually completed a STEM major. Those who switched into STEM had stronger grades in mathematics and science than those who left.
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• Switching in or out of the STEM pathway during middle and high school was associated in both directions with changing attitudes to mathematics and science, and their usefulness. Student attitudes to mathematics and science play a significant role in decisions to persist.

• Students who reported that their teachers emphasized learning facts and rules in mathematics were significantly less likely to complete a major in STEM. In science, students who reported their teachers spending more time lecturing or that they used books to show how to do labs were also less likely to continue in the STEM pipeline. Students who in 12th grade indicated an intended major in STEM were more than 3 times as likely to earn a STEM degree.

• University students with a pattern of failure or change of degree were less likely to earn a STEM degree than those with stronger marks and a consistent trajectory.

• Access to STEM qualifications did not seem to be restricted to those from advantaged financial situations.

Maltese argues from these findings that a policy aimed at inducements or requirements to get students to take more rigorous programs in mathematics and science, or creating a standardized progression of courses, will not necessarily lead to an increase in STEM participation. Rather, increasing interest in these subjects and demonstrating their utility to students in their current and future roles may pay greater dividends. The need for this earlier than Year 9 has previously been discussed.

5.1.2 Identity

Contemporary youth, like the adult populace, is not a homogeneous population. Young people in today’s society see themselves as free to choose their address, religion, social group, politics, education, profession, sexuality, lifestyle and values (Beck & Beck-Gernsheim, 2002). This is a considerable transformation from 40 years ago when choice was much more limited and expressed predominantly in terms of a young person’s choice of profession. Johanna Wynn (2004), in a five-year longitudinal study of 200 young people immediately post–degree, argued that uncertainty and change are the conditions that predominantly shaped her subjects’ values and choices. They valued flexibility – the capacity to make choices and be proactive about job mobility – rather than predictability, as a basis for future security. Her subjects valued personal autonomy and responsiveness as capabilities they worked on developing, as part of a ‘self as project’ outlook on their pathways. They valued the notion of a career, but saw this in terms of flexible and opportunistic job shifts aimed at developing a flexible CV, rather than in terms of a stable and continuous job.

Adolescence is a particularly significant time when young people are first confronted by the need to construct their sense of self. As has been well documented, this situation creates a state of insecurity or moratorium (Head, 1985). In some senses, this angst is not new. All young people have had to
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undertake this process. What is new is that the range of choices presented to contemporary youth is now much greater. The decision-making landscape that young people negotiate as they select their school subjects, decide who they want to be, and aspire for fulfilling futures is complex terrain, and analysis is complicated by that fact that the barriers that hinder young people’s decision-making are not always immediately apparent and will change over time, and change in degree, as students grow and develop (Alloway et al., 2004; Engineering and Technology Board, 2005a; Fouad, Hackett, Haag, Kantamneni, & Fitzpatrick, 2007; McMahon & Patton, 1997; E. Walker, 2007; K. Walker, 2006; K. Walker, Alloway, Dalley-Trim, & Patterson, 2006).

There is a significant body of research on the impact of identity on the education-related choices of young people (Louise Archer, Hollingworth, & Halsall, 2007; L. Archer, Pratt, & Phillips, 2001; L. Archer & Yamashita, 2003; Boaler, 1997; Connell, 1989; Francis, 2000). Many of these choices—whether or not to continue, which subjects to continue with, who I will aspire to become—impact upon each student’s success or failure in fulfilling his or her aspirations. Fouad, Byars-Winston and Angela (2005) found in the U.S. context that while race does not have an impact on students’ career aspirations, it impacts on the barriers that students encounter as they take action to fulfil those aspirations. From this, it is clear that ‘choice’ is a highly constrained concept in the context of education, an experienced as limited or expansive depending upon a number of factors, including prior academic performance, school location, and prior choices of an equally constrained nature.12

Identity is a construct that goes beyond concerns such as curricula, intrinsic interest or career intentions, to instead frame aspirations and perceptions in terms of social relationships and self-processes (Lee, 2002). Identity theory understands that the self (or selves) is bounded by social structures, and that interactions shape the organization and content of self. Analysing decisions to participate in and choose STEM courses and careers through an identity framework, involves emphasising relationships with family, teachers, peers, and others, and identifying the degree of synergy, or disjuncture, experienced by young people between their everyday lives and their educational pursuit of STEM (See Louise Archer et al., 2007).

A number of authors argue that identity development is an important but neglected factor in mathematics education (Boaler, 2002; Boaler, William, & Zevenbergen, 2000; Schreiner & Sjöberg, 2007; Sfard & Prusak, 2005). Continuing or not in the mathematics stream is a function of identity construction in that students learn how to be a mathematics student, and gain an impression of the role or identity of a mathematician (Boaler, Wiliam et al., 2000).

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12 “Bourdieu noted that the ‘habitus,’ which includes an internalization of the power and status relationships between groups of people in a society, ‘continuously transforms necessities into strategies, constraints into preferences and without any mechanical determination, it generates a set of ‘choices’ ... It is a virtue made of necessity which continuously transforms necessity into virtue by inducing ‘choices' which correspond to the condition of which it is the product’” (Correll, 2004, p. 95).
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Lee (2002) used a structured equation modelling approach to examine the responses to a series of surveys, of 320 high achieving students enrolled in a number of summer programs designed to foster interest in STEM courses. His findings showed the usefulness of the identity construct in analysing student response to the programs, which were framed around relationships. He found no lasting impact on the durability of impact of these high profile summer schools, but found significant gender differences in that girls were more influenced by program activities and relationships than boys, who had more stable and durable identities based around past activities and home relationships. Lee concludes that it is important to provide positive, meaningful relationships around STEM activities to maintain talented students in the STEM pipeline, and that this is particularly important for girls.

Schreiner (2006) as argued in the previous section, interprets the low recruitment into STEM subjects in wealthy, modern societies in terms of changing values of youth in late modern societies. This analysis has a significant identity component. Schreiner and Sjoberg (2007, p. 242), draw on three perspectives to make sense of the data:

1. Issues that are perceived as meaningful for young people in a country are dependent on the culture and the material conditions in the country

2. An educational choice is an identity choice (see also Aikenhead et al., 2006)

3. Young people wish to be passionate about what they are doing and they wish to develop themselves and their abilities. They experience a range of possible and accessible options regarding their futures, and among the many alternatives, they choose the most interesting.

In regard to the first perspective, for early industrial countries where the major national project is towards progress and growth and building the country, scientists and engineers are seen as crucial for people’s lives and well being. In poorer countries, young people have a rather heroic image of scientists. In late modern societies, these values have changed.

Schreiner and Sjoberg speculate that the main reason that young people, especially girls, are reluctant to participate in the physical sciences is because they often perceive the identities of engineers and physicists as incongruent with their own. There is an abundant literature (Boaler, 1997; Lightbody & Durdell, 1996; Mendick, 2006; Walkerdine, 1990) which argues that STEM subjects and careers have a masculine image that leads girls to reject identities connected with STEM. Schreiner and Sjoberg (2007) argue that, if this perspective is correct – and that the identities of youth in late modern societies are connected with late modern values such as self realisation, creativity and innovation, working with people and helping others, and making money – then attracting more students into STEM pathways will require upgrading the images of STEM work to include these things, and updating the content and practice of school STEM subjects to make these values more apparent.
5.1.3 Gender

Gender impacts significantly upon student career aspirations and subject selection. Research by Helme and Lamb (2007), Watt (2005, p. 21) and Forgasz (2006a, 2006b) finds that there are more female students choosing lower-level math courses than males, and that this difference is not based upon mathematics achievement. Controlling for prior performance, female students are over-represented in lower-level math courses and under-represented in higher-level math courses. Males are more likely to continue in STEM study than their female peers irrespective of past performance. When analysed more closely, gendered rates of participation are significantly variable between subjects. Males make up 62% of the enrolments in the physical sciences in Australia, while females make up 60% of the enrolments in the biological and other sciences (Ainley & Elsworth, 2003; Fullarton, Walker, Ainley, & Hillman, 2003). Males “clearly predominate in technical studies and computer studies” (Ainley & Elsworth, 2003), are over-represented in mathematics, and make up about a four fifths of enrolments in physics and engineering (OECD, 2007a). Parker, Rennie and Fraser (1996) documented significant differences in participation in STEM courses and occupations, and trace this to the gendered construction of STEM subjects. Kenway and Gough (1998), in reviewing girls’ attitudes to science, point out the subtle gender stereotyping that is characteristics of science subjects, particularly the physical sciences.

Differences between girls’ and boys’ interests are demonstrated by findings of the Relevance of Science Education (ROSE) study. The questionnaire responses from an English cohort were summarised by Jenkins and Pell (2006, p. 6).

When asked what they wished to learn about, there are marked differences in the responses of boys and girls. For girls, the priorities lie with topics related to the self and, more particularly, to health, mind and well-being. The responses of the boys reflect strong interests in destructive technologies and events. Topics such as ‘Famous scientists and their lives’ and ‘How crude oil is converted into other materials’ are among the least popular with both boys and girls. ... There are major differences in the out-of-school experiences of boys and girls. Those of girls are associated with activities involving the natural world, such as planting seeds or crafts such as knitting or weaving. In the case of boys, activities that might be described as mechanical are to the fore, although the engagement of girls with the use of simple tools should not be overlooked.

There are particular social factors that operate to support or discourage the participation of women in STEM. These are linked with identity and self efficacy issues and the support offered both within science and mathematics classrooms, but also to broader patterns that shape identity. Cultural stereotypes about gender have an impact on students’ career aspirations and subject choices (Correll, 2001, 2004). Female students are more likely to aspire to non-STEM careers. This aspiration is generally not articulated as a disinterest in STEM, but rather as a competing interest that pulls females away from STEM. The OECD’s Education at a Glance (2007a) shows that compared to their male peers, female students in Australia continue to underestimate the relevance of mathematics to their lives. Alloway et al. (2004) argue that gender stereotypes tend to make some pathways seem unattainable. Their study found evidence of a strong social militancy that restricted the range of student choices by means of gender stereotyping. Such militancy is most visible as peer pressure, but other
Opening up pathways into STEM

more subtle means of reiterating gender stereotype are expressed in students’ daily rituals, cognitive style, as well as teachers’ and parents’ gender-coloured expectation of student achievement (Louise Archer et al., 2007; Butler, 1999; Correll, 2001; Creed, Patton, & Bartrum, 2004; W. Patton, Bartrum, & Creed, 2004).

There is a considerable volume of feminist literature on how gender identities and inequalities are implicated in the channelling of girls into particular gendered choices and educational/occupational routes (for instance the classic work of people like Dale Spender, Gaby Weiner, or Valerie Walkerdine) but more recent work has looked at how gender identities also inflect what girls and boys see as normal and desirable in relation to ‘doing boy’/’doing girl’ (Connell, 1989; Connolly, 2004; Francis, 2000; Reay, 2001; Skelton, 2001). There has been a strong strand of feminist critique that links gender identity and subject choice with the gendered nature of subjects (Boaler, 1997; Mendick, 2006; Walkerdine, 1990). Belenky et al. (Belenky, Clinchy, Goldberger, & Tarule, 1986) argue that there are distinctive gendered ways of knowing that frame responses to subjects and institutional practices. Harding (1993, 1998) questions the objectivity of science and argues that school science should reflect a feminist epistemology that emphasises the cultural antecedents of scientific practices, rather than the absolutist presumptions of truth and objectivity that dominate current curricula.

Johnson (2007) described barriers to science-interested minority females’ continuing participation in STEM such as lack of sensitivity to their difference, discouragement, and a sense of alienation from school science. This echoes the findings of Lindahl (2003, 2007). Johnson described how even a laudable activity like asking questions of students in lectures can advantage white male students who are more competitive and confident, and cause women to feel a loss of status, and rob them of the only opportunity to get to know their teachers on a personal level. In describing the experience of these women moving through undergraduate science, Johnson concludes:

The first step in making science more encouraging … is for scientists to recognize that science has a culture, and that certain types of students may find it challenging to understand and navigate this culture … if scientists cannot let go of narrow, decontextualized presentations of science, they will have difficulty winning the respect of women who see their interest in science as inextricably united to their altruism. … Science has a rich history of service to humanity. When scientists present their lectures with no allusion to this context, it may not because they are uninterested in it but only because such ties are so obvious to them already (p. 819).

In a symposium organised at the conference of the National Association for Research in Science Teaching in Baltimore in 2008, Johnson and her co-presenters summarised their argument thus: “if you want to discourage someone from continuing in a subject, the very best way is to make them feel they don’t belong.”

Young women need additional ‘supports’ to continue in STEM (Adamuti-Trache & Andres, 2007; Hackett, 2006; Victorian Parliament Education and Training Committee, 2006). Owen et al. (2007) describe how the research points to the need for early intervention if we are to encourage girls to engage with STEM:
Early learning experiences have a major impact on later achievement in math, science, and technology (Strauss, 1988; Huang & Du, 2002). Stereotypical gender bias alienates girls from these fields early in their education (Darke et al., 2002), and even 6-year-olds of both genders associate science with males (Hughes, 2002). As occupational stereotypes have a profound effect on educational and career choices (Hughes, 2002), the effort to eliminate gender bias in education and the workplace should attend to early schooling (p. 1463).

Classroom approaches that have been argued to enhance girls’ engagement in science and mathematics include:

- low levels of competitiveness and of drill and practice;
- high levels of teacher attention to all students including the development of a positive self image in relation to the discipline, hands on activities;
- the use of real-life materials that cater for the specific interests and experience of girls; and
- single sex classes (Gilbert, 1996; Haussler & Hoffmann, 2002).

A response to these findings for science is to teach the concepts in specific contexts that represent life in the real world (Hart, 2002; Whitelegg, 1996; Whitelegg & Edwards, 2001). In Hart’s case, the establishment of a contextually framed post-compulsory physics curriculum was opposed by disciplinary interests. In mathematics, however, there have been several studies that show both boys and girls can intellectually engage with the development of new conceptual understandings in mathematics without the need for a context beyond mathematical exploration (Lampert, 2001; Williams, 2002a). Collaborative inquiry based approaches to teaching and learning are consistent with these identified needs for learning environments that encourage the participation of girls and have been shown to be engaging for boys as well (Barnes, 2000) while maintaining intellectual quality.

In mixed gender classes teachers have been shown to subscribe to subtle, or not so subtle, expectations that boys have a natural inclination towards and talent for physical sciences and mathematics, and this is relayed through differential attention and through language, and reinforced by similar presumptions by boys. This is exacerbated by the demand for attention of many boys and the willingness of many girls to put up with a limited amount of teacher attention. Under these conditions, girls pick up messages of ‘otherness’ in relation to these subjects. One response has been to establish single-gender classes, either across the curriculum, or specifically in mathematics and science to give girls access to more teacher time. Haussler and Hoffmann (2002) undertook an experimental study where physics was taught within single sex classes, using a contextual approach (with features such as providing first hand experiences, linking content with prior experiences, encouraging discussion of social importance, relating physics to the human body). The experimental group was significantly improved compared to the control group, for both girls and boys, on a range of measures including achievement, interest and self concept. Haussler and Hoffmann found that the main effect was the single sex setting, with the interest based curriculum also achieving a significant improvement. The authors point out the difficulty of definitively claiming an advantage for single sex classes under all curriculum conditions.
The issues associated with gender and engineering are highlighted by three papers given at the 9th Australian Women in Engineering forum held in Melbourne in 2003. Darby et al (2003), from a study involving survey and focus group interviews with 14-15 year old girls, identified a number of barriers operating against an engineering career choice. These young women were not able to create links between their own interests and what engineers do because of lack of knowledge of what engineering involves, the subsequent falling back on traditional stereotypes of a male dominated industry, and lack of personal knowledge of engineers who might act as role models. Burrowes (2003), in a study of the language of an engineering classroom environment, identified language as a significant aspect of the creation of a gendered classroom environment. She identified persistent comments with sexual connotations and examples of sexist language that treated women as objects and excluded them from the technological world. Bastalich et al. (2003) conducted a qualitative study of women’s and men’s experiences in a range of engineering disciplines, industry sectors and work locations. They identified a significant contributor to reasons for women leaving the profession to be a feeling of alienation within the prevailing workplace culture, more so than family responsibilities, or lack of confidence, technical expertise, or interest in engineering work compared to men. The report of the Australian Council of Engineering Deans (R. King, 2008) raised the issue of lack of public knowledge of the nature of engineering work, and acknowledged issues of gendered workplaces. Wood, Hjalmarson, & Williams (in press) tells part of this story finding that it can be harder for women to establish themselves as credible in group work where the discourse around tasks focus on stereotypical male experiences.

There have been significant campaigns to represent the participation of women in science, technology, engineering and mathematics careers. For example, Engineers Australia designated 2007 the Year of Women in Engineering and initiated many activities including the publication of significant accomplishments of twelve women engineers, under the title ‘Stories of Inspiration’ (Engineers Australia, 2007). This reprises similar campaigns in previous decades (for example Bielski, 1989). Improvements have been uneven with participation in undergraduate chemistry rising to roughly equal numbers whereas in engineering it languishes at about a fifth following strong campaigns in both. There is no research showing a causal connection between these campaigns and participation levels. Appendix 3 describes a number of initiatives aimed at these barriers.

In terms of national systemic factors Van Langen and Dekkers (2005) looked at international enrolment data and concluded that successful participation in STEM at college level was associated with less specialisation at earlier stages of secondary and post secondary education, allowing more entry points into the STEM pipeline. Van Langen, Bosker and Dekkers (2006) reported on PISA data which correlated female participation in tertiary STEM education to measures of integration of a country’s educational system, measured by the level of tracking, grade differentiation, gender and socio-economic separation, and differences in quality between schools. Australia was found to perform positively, being in the top quartile on the integration measure.
There is an urgent need to reduce the prevailing gap in educational and post-school outcomes between indigenous and non-indigenous students in Australia. Compared with 76.8% of all non-indigenous students, only 39.5% of Indigenous students progressed to Year 12 in 2004 (AESOC Senior Officials Working Party on Indigenous Education, 2006). Furthermore, Thompson and De Bortoli (Thomson & De Bortoli, 2008a) highlight the “wide gap in performance” between indigenous and non-indigenous students in Science, Reading and Mathematics literacy. The authors found, from data collected in PISA 2006, that in “scientific literacy the performance of Indigenous Australians was 88 score points lower than that of non-Indigenous students” (2008b, p. 12). Aikenhead and Ogawa (2007) argue that school science tends to portray scientific ways of knowing as free from value and without context. This way of presenting school science, without multiple or contested views, tends to marginalize some students on the basis of their “cultural self-identities” (Aikenhead & Ogawa, 2007, p. 540). Aikenhead argues elsewhere (Aikenhead, 2001b, p. 338) that only a small minority of students’ “worldviews resonate with the scientific worldview conveyed most frequently in school science (Cobern & Aikenhead, 1998).” All other students experience the single-mindedness of school science as alienating, and this hinders their effective participation in school science. These feelings of alienation are generally more acute for Indigenous students “whose world-views, identities, and mother tongues create an even wider cultural gap between themselves and school science” (Aikenhead, 2001b, p. 338). Aikenhead (2001b) emphasizes the importance of cross-cultural science teaching, which recognizes Aboriginal knowledge and languages as an asset that can be tapped into to empower students and help them become resilient. Research on the needs of indigenous students has also been ongoing in mathematics (Howard & Perry, 2003, 2007; Sullivan, Zevenbergen, & Mousley, 2003). Michie (2002) also emphasizes the importance of including Indigenous science in the Australian school curriculum. In order to teach science cross-culturally, O’Connell suggests that the science teacher must

become a tour guide or 'broker' (Roberts, 1998) to ensure that Indigenous students are offered a flexible and playful approach to the melding of the two cultures. The aim for all teachers of science should be to endeavour to make Indigenous students feel at ease, particularly in a culture which is unfamiliar to them. In this case, Western science.

Further examining the barriers that impede the success of indigenous people in science, McKinley (2005) identifies the difficulty experienced by Maori women scientists in managing inconsistent images of themselves — as women, as Maori, as scientists — and argues that competing legacies of

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A current Griffith University-led research project is working with a range of Indigenous communities in the east Kimberley region on a new mathematics pedagogy developed by Stanford University and designed for low-performing students in a Californian School. As reported on Radio National’s Bush Telegraph on 28 April, 2008, the methods consist in part of allowing students to explore mathematics problems in their own language in order to reduce the “cognitive labour” involved with translating back and forth between classroom-English and one’s everyday language. This project is in its early stages, and runs until 2011.
science, knowledge, and culture have built strong cultural stereotypes of Maori women, who in interviews describe being discriminated against, prejudged and overlooked in their scientific roles. In mathematics, the view of the individual as a member of a community and the need to defer to more respected members, and not to draw attention to self as an individual are contrary to successful mathematical activity during collaborative group work where students are expected to evaluate the ideas of others (Sullivan et al., 2003).

5.1.5 Cultural capital

Adamuti-Trache and Andres (2007) draw upon Pierre Bourdieu’s work in the sociology of education to examine the level of influence that parents have in transmitting cultural values and practices to their children, and thus disposing them, or not, toward STEM fields of study. Students with university-educated parents are shown in this study to decide earlier about their career directions, and are more likely to choose science subjects. The transmission of cultural capital exacerbates inequalities in the education system, and under-prepares, or prematurely restricts the pathways of students whose parents and family contexts do not facilitate, encourage, assist and fund academic pursuits in STEM. There is also evidence that the job satisfaction of parents in STEM careers, particularly the mother, can have significant influence on children’s career aspirations. Christine Brew (2000, 2003) discusses a powerful dynamic that developed between women who had poor results in mathematics at school, but subsequently returned to further study of mathematics as an adult, and their children. These mothers developed new abilities to assist their children with mathematics homework and were helped by their children when they experienced problems themselves. Both the mothers and the children found the interactions assisted them in pursuing their studies in mathematics and motivated them to do so.

The Department of Education Science and Training’s Youth Attitudes Survey (2006c) found that the skill level and education of a student’s parents had no effect on levels of participation in mathematics in Year 11 and Year 12. However, students who chose science and technology subjects reported overall higher levels of parental influence upon their decision-making. This survey also found that parental skill and education level influenced students’ post-school preferences, observing that

A greater percentage of School Leavers whose parents were professionals or semi-professionals or had a university qualification went to university than those from other categories. A greater percentage of School Leavers whose parents had a trade or advanced clerical skills ended up at VTE (p. 36).

Haeusler and Kay’s (1997) study also found that parental and teacher advice played a far more prominent role in students’ selection of mathematics and science subjects than it did in their selection of other school subjects. Watt and Bornholt (2000, p. 1494) noted that the level of parental influence at senior secondary school is less notable than in earlier years. Students “make choices of subject levels in senior high school mostly with reference to themselves, rather than their parents, and in particular to perceived natural talent and interest in the subject (Watt, 2005).”
Lyons’ (2006b) study of high-performing Year 10 students when choosing senior subjects, involved questionnaire data from 196 students, and more detailed interview data from 37 students, concerning their attitudes to science and the backgrounds to their choice. Lyons (2006b) identified from his interview data that the students choosing physical science were those who had (a) supportive relationships with members of their family, (b) parents who emphasised the strategic value of formal education and (c) family members advocating or supporting an interest in science. He also found that students taking physical science had higher levels of self-efficacy, and identified this quality as being instrumental in the decision to take difficult science subjects. He explained these findings in terms of ‘cultural and social capital’ associated with supportive family relationships and family views that were aligned with school science.

Lyons’ interviewees expressed no view on particular career or status implications of choosing science. He argued that it would be wrong to think of the diminishing numbers in post-compulsory science as a consequence of students being drawn away by more attractive options, or by a lack of career prospects, and describes how:

> it became increasingly obvious that the most cogent single force acting against the choice of physical science courses was the culture of school science itself. While emphasising the status and strategic utility of physical science courses, students in this study considered school science to have fewer intrinsically satisfying characteristics than it might have (Lyons, 2006b, p. 308).

Given this, Lyons argues that it is school science that needs to be the focus of change, rather than a recasting of tertiary science courses or an emphasis on scientific career opportunities. He argues that the lack of interest in school science means that students are being discouraged from continuing STEM study at an early stage, in particular in physical science, and considerable cultural and social capital is needed to overcome this hurdle.

### 5.1.6 Student aspirations and decision-making

The factors affecting how young people make choices at age 14 and 16 were the subject of a recent UK study conducted by the National Foundation for Educational Research for the UK government (Blenkinsop, McCrone, Wade, & Morris, 2006). They point to the work of Bandura et al. (2001) who perceived self-efficacy (the belief that one has the power to produce effects by one’s actions) as having greater predictive power in occupational choice than other theories. Following “an analysis of socio-cognitive data from 272 children, they concluded that self-efficacy emerged as a result of the interaction between ‘socioeconomic, familial, academic and self-referent influences [operating] in concert to shape young people’s career trajectories’” (Bandura in Blenkinsop et al., 2006, p. 4). Family socio-economic status, they argued, had only an indirect effect on young people’s perceptions of their capabilities. Higher status parents had raised parental aspirations which, in turn, were passed on to their children both as expectations and belief in their own capabilities and academic aspirations. Moreover, young people’s beliefs in their academic capabilities, rather than their actual academic achievement,
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‘had the most direct pervasive impact on their judgments of their occupational efficacy’ (Bandura in Blenkinsop et al., 2006, p. 4).

The NFER report itself points to the complex nature of young people’s decision making. Major findings, for the purpose of this review, would be that young people, in general, were influenced by their perception of a subject, both in terms of their enjoyment of it and its apparent worth for future careers, as well as their perception of their ability at a subject. However, where students were provided with a wide range of information, advice and guidance of an impartial nature, there was evidence that they had been influenced by structural factors (such as careers education and guidance and talks with teachers). In contrast, where that was not the case, students appeared more influenced by factors associated with other agents, with young people turning to their friends, family and other external sources of influence. The policy implication of this is that improving the structural support provided by schools will expand students’ decision making capabilities. The research identified eight ‘educational mindsets’ held by young people based on their orientation (future or present); their outlook about the future and the level of optimism they hold; their tolerance of risk; and how they think success comes about. These mindsets were confident aspirationalists; determined realists; long-term preparers; indecisive worriers; short-term conformists; unrealistic dreamers; comfort seekers; defeated copers. Space does not permit a presentation of how these mindsets individually influence decision making but links with optimism and lack of optimism are implicit. The major finding of interest for this review is that there appeared to be a link between schools which were particularly ‘effective’ (in relation to staff expectations, leadership, curriculum management) and students who were making arguably the most effective and thought through decisions (the most ‘positive’ mindsets were clustered in such schools). Links between these schools and Glover’s et al. (1998) resilience building schools need further exploration. Though, arguably, this link may be correlational rather than causal, it points to the fact that supportive, structured environments aid students to come to a positive view about their potential future careers.

Fouad, Hackett, Haag, Kantamneni, and Fitzpatrick (2007) conducted a study of supports and barriers to mathematics and science choice, looking particularly at gender differences and differences by developmental level. They used a questionnaire instrument with 1151 students from middle school, high school and college, their instrument development and analysis were based on social cognitive career theory (Lent, Brown, & Hackett, 2002), which looks at student interest and aspirations in terms of the effects of interactions between personal factors and learning experiences on self efficacy and outcome expectations (see Figure 5.2).
They found that for both math and science, across genders and developmental levels, the key barriers included the presence / absence of subject test anxiety, and perceptions of subject difficulty. The top supports were parental expectation to take more classes or choose a career related to mathematics or science, and for middle and high school students, their teachers’ expectations of success and teacher support to do well. They used analysis of variance tests to examine the differences in perceptions of mathematics and science barriers between developmental levels, and separately again between males and females. They found a number of significant differences with developmental level, although many of these had small effect sizes. Most of these items became more influential as a barrier or less influential as a support, with age. For mathematics, the top items were: parental knowledge (as a support), exposure to inspirational teachers, parental guidance in mathematics decisions, exposure to career guidance, knowledge of successful adults, and self-evaluation of ability. For science, the top items were science interest, the existence of student disruptions, and exposure to inspirational teachers. In the reverse directions, college students perceived evaluation of future science use, and friends’ interests in science, as being supports more so than for school students.

In the gender analysis, the major item of difference, by far, for both mathematics and science, was teacher gender stereotypes for mathematics/science performance. Teachers’ gender stereotypes for performance, or beliefs that one gender was more skilled, emerged as the largest difference between boys and girls across all developmental levels for both math and science. In other words, our male participants perceived that teachers thought boys were better than girls in both math and science, and this perception acted as a support in influencing their math course and career selection. While, our female participants agreed that teachers thought boys were better than girls, for them this perception acted as a barrier. (Fouad et al., 2007, notes to slide 8)
The findings indicate that boys and girls at different levels put barriers and supports together in a different manner. They echo the findings from many other studies of student aspirations, with major themes including personal attributes of interest, self efficacy, identity in relation to role models and career, and knowledge and support in relation to career.

Figure 5.3: What variables predict students’ choices to pursue mathematics courses or a mathematics career? The numbers in brackets are values of $R^2$ for each item.

<table>
<thead>
<tr>
<th>College Boys (4 predictors) ($R^2=0.59$)</th>
<th>College Girls (9 predictors) ($R^2=0.39$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Math interest (0.24)</td>
<td>• Math interest (0.11)</td>
</tr>
<tr>
<td>• Evaluation of future math use (0.27)</td>
<td>• Parental expectation to take more math classes/choose math career (0.21)</td>
</tr>
<tr>
<td>• Self-evaluation of math ability (0.22)</td>
<td>• Social anxiety associated with math performance (0.13)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>High School Boys (11 predictors) ($R^2=0.41$)</th>
<th>High School Girls (5 predictors) ($R^2=0.33$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Parental support in math decisions (0.32)</td>
<td>• Math career goals (0.24)</td>
</tr>
<tr>
<td>• Parent’s evaluation of math utility (0.29)</td>
<td>• Math interest (0.16)</td>
</tr>
<tr>
<td>• Academic preparation in math (0.21)</td>
<td>• Parental expectation to take more math classes/choose math career (0.18)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Middle School Boys (6 predictors) ($R^2=0.48$)</th>
<th>Middle School Girls (5 predictors) ($R^2=0.39$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Self-evaluation of math ability (0.56)</td>
<td>• Math interest (0.28)</td>
</tr>
<tr>
<td>• Exposure to racially-similar role model in math (0.35)</td>
<td>• Exposure to math career guidance (0.21)</td>
</tr>
<tr>
<td>• Social anxiety associated with math performance (0.24)</td>
<td>• Parental support in math decisions (0.24)</td>
</tr>
</tbody>
</table>

A further analysis examined the variables that most strongly predict students’ choices to pursue mathematics or science courses or career. The figures show the top three variables for boys and for girls, at each developmental level, for mathematics (Figure 5.3) and science (Figure 5.4). These again pick up the key factors of interest, anxiety and self efficacy, and career knowledge and support. They emphasise however the importance of parental expectations and support at all levels, more so than direct comment on teacher or curriculum characteristics. These will, however, be hidden in variables such as interest and anxiety.
Figure 5.4: What variables predict students choices to pursue science courses or a science career? The numbers in brackets are values of $R^2$ for each item.

<table>
<thead>
<tr>
<th>College Boys (4 predictors) ($R^2$=0.45)</th>
<th>College Girls (7 predictors) ($R^2$=0.52)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Science interest (0.34)</td>
<td>• Science interest (0.32)</td>
</tr>
<tr>
<td>• Friends’ evaluation of science ability (0.31)</td>
<td>• Parent’s evaluation of science usefulness (0.20)</td>
</tr>
<tr>
<td>• Parental expectation to take more science classes/ choose science career (0.15)</td>
<td>• Parental expectation to take more science classes/ choose science career (0.16)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>High School Boys (7 predictors) ($R^2$=0.44)</th>
<th>High School Girls (8 predictors) ($R^2$=0.48)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Science interest (0.22)</td>
<td>• Parental expectation to choose science career (0.29)</td>
</tr>
<tr>
<td>• Parental expectation to choose science career (0.22)</td>
<td>• Science interest (0.20)</td>
</tr>
<tr>
<td>• Exposure to science career guidance (0.21)</td>
<td>• Self-evaluation of science ability (0.20)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Middle School Boys (5 predictors) ($R^2$=0.32)</th>
<th>Middle School Girls (3 predictors) ($R^2$=0.21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Self-evaluation of science ability (0.36)</td>
<td>• Science career goals (0.23)</td>
</tr>
<tr>
<td>• Science anxiety (0.32)</td>
<td>• Parental help with science homework (0.20)</td>
</tr>
<tr>
<td>• Parental guidance in science career/course decision (0.25)</td>
<td>• Academic preparation in science (0.18)</td>
</tr>
</tbody>
</table>

### 5.1.7 Indicators of success in STEM

Some young people do not experience any barriers as they transit between their everyday experience of life outside of school and their experience of the STEM classroom. The whole STEM pathway is indeed experienced by some young people as smooth and trouble free. Aikenhead and Jegede (1999), drawing upon the work of Phelan et al. (1991) and Costa (1995), describe such smooth transitions as an experience of congruence between family culture and science classroom culture, they talk about feeling “comfortable” (Aikenhead & Jegede, 1999, p. 270).

The factors that influence student subject choice are interwoven, and are not always easy to separate from one another. For example, Fouad et al. (2007) identify the following barriers and supports in student choice to continue math courses to upper secondary level:

In general, for both college boys and girls, the strongest predictor for pursuing a math career was math interest. For high school boys, the strongest predictor was parental support in making math decision and for high school girls, the strongest predictor was possessing math-related career goals.

Watt and Bornholt (2000, p. 1498) find equally interwoven factors, showing that the “plans for participation in senior mathematics courses were substantially explained (64% of the variance) by contributions from gender ($p = -0.10$), current course level ($p = 0.33$), perception of talent ($p = 0.22$),...
perceived effort \( (p = -0.15) \), and interest \( (p = 0.29) \).” What emerges from the research, across a number of countries, is the complex interplay between various factors that determine at each point in a students’ school life their aspirations concerning future subjects, and future careers. In addition to those factors discussed above, below is a summary of factors that are found to correlate with success and persistence in STEM.

### 5.1.7.1 Student achievement

High achievement scores generally indicate persistence in STEM (Schneider, Swanson, & Riegle-Crumb, 1998). Students who persist in STEM have usually performed well or very well in Year 9 mathematics courses (Committee for the Review of Teaching and Teacher Education, 2003b), or took high school advanced mathematics courses (Rose & Betts, 2001).

There is evidence of a strong correspondence between specialising in STEM in Year 12 and commencing STEM-related higher education (Committee for the Review of Teaching and Teacher Education, 2003b). Maltese (2008) cites many quantitative studies from the US which demonstrate strong links between patterns of subject choice in high school and early college years, and participation and eventual graduation in STEM college courses, but points out, with Federman (2007), the selection bias inherent in such data, and the need to establish underlying factors for both school and college participation. There is a question that follows from these seemingly self-evident findings — who have we lost along the way who was capable of STEM participation?

### 5.1.7.2 Student interest and boredom

As discussed above, young people who continue in STEM education and employment tend to demonstrate a strong interest in STEM subject content and learning (Beavis, 2003; Engineering and Technology Board, 2005a; Fouad et al., 2007; Hackett, 2006; Maltese, 2008; McInnis et al., 2000; OECD, 2006; Watt, 2005; Watt & Bornholt, 2000). Student interest is an important determinant of senior science participation (Ben Zvi & Hofstein 1987; Tamir & Gardner 1989) and once prior achievement has been accounted for, interest correlates strongly with choice (Steinkamp & Maehr 1983). DEST (2006e), Helen Watt (2005; Watt, 2006) and McPhan et al. (2008) corroborate these findings in an Australian context, observing that interest in mathematics is a strong predictor in pursuing math study at upper secondary level (DEST, 2006e; McPhan et al., 2008; Watt, 2005; Watt, Eccles, & Durik, 2006). Williams (2000) found that learning higher level mathematics through complex problems and collaboration led to increased participation of girls (and boys) in advanced mathematics with the proportion of girls in this subject increasing over the three years. Students in these classes performed fourth best out of the government schools in Victoria in this advanced mathematics subject even though the measure was biased against schools with a small number of classes.

The DEST (2006c) Youth Attitudes Survey shows that of the surveyed students who were not interested in STEM, large numbers reported boredom (56% Science; 58% Maths; 50% Technology), no real life examples (69% Science; 32% Maths; 22% Technology), teachers (17% Science; 32% Maths; 33%
Opening up pathways into STEM

Technology), poor image (17% Science; 6% Math; 34% Technology) and not enough projects (14% Science; 20% Math; 30% Technology) as the most important reasons for their disinterest.

These responses paint an interesting picture when compared with students who were interested in STEM, most notably for the strength of positive feelings, where enjoyment was most often reported as the critical factor (86% Science; 64% Math; 84% Technology). The second most important factor in cultivating mathematics interest was parental encouragement (58%), and teachers (58%). The next most important factors for Science and Technology students were projects (55% Science; 66% Technology) and real life examples (69% Science; 66% Technology).

What these figures indicate is the different patterns of response to STEM subjects, and different expectations of what they should be offering. Whereas the population of students who were not interested in STEM tended to be overall less decisive—and understandably so—about the reasons for their disinterest, with large numbers reporting neutral or not important responses for most indicators, the interested student population indicates an overall strong engagement with each subject.

5.1.7.3 Student aspirations

Students who persist in STEM are more likely to have career aspirations in science and/or mathematics (Cleaves, 2005; Hackett, 2006; Osborne et al., 1997; Tai, Qi Liu, Maltese, & Fan, 2006). Helme and Lamb (2007), and Forgasz (2006b) identify tertiary requirements and heavy competition in the final year of high school as having an influence on student subject choice. Broadly speaking, students choose not to do subjects they think will be difficult, or that they expect not to do well in (Forgasz, 2006b; McPhan et al., 2008). Students with ambitions to enter highly competitive tertiary education courses tend to select subjects that are weighted according to level of difficulty, and will often complete one Year 12 mathematics subject in Year 11. The impact of these decisions on students’ mathematical understanding requires further research because such pathways may be disadvantageous.

5.1.7.4 Peers

Students who continue with STEM study tend to have a STEM-involved peer group (Hackett, 2006; Lord, Harland, & Giulliver, 2006). Successful students are viewed by their peers as STEM-competent (Hackett, 2006). Although students rarely report their peers as an influential factor in their subject choices (Alloway et al., 2004; DEST, 2006c), there is a reasonably consistent correlation found between students’ choices and their peer group, indicating that this may not necessarily be a conscious decision, but that peers do indeed impact upon student choices (or alternatively that those with similar interests are likely to become friends).

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14 Helme, personal communication, publication forthcoming. The ‘up-scaling’ of particular subjects when calculating tertiary ENTER scores as a factor influencing student subject selection is also evident to a small degree in findings by Haeusler and Kay (1997), the Australian Council of Engineering Deans (King, 2008), likewise observes the impact of current assessment regimes on student choices.
5.1.7.5 Socio-economic status

Students who persist in STEM are more likely to have higher socio-economic status (See Committee for the Review of Teaching and Teacher Education, 2003b; Sue Helme & Lamb, 2007; Lamb & Ball, 1999; Thomson & De Bortoli, 2008a). “In chemistry and physics the participation rate for Year 12 students from the highest of four socioeconomic groups is more than twice that for students from the lowest socioeconomic group. In biology the difference between the top and bottom socioeconomic groups was less than in chemistry and physics” (Committee for the Review of Teaching and Teacher Education, 2003c, p. 11). However, there continue to be conflicting accounts of the impact of SES on persistence in STEM, which raise numerous questions about whether SES provides the most useful account of participation rates. As there are likely to be more stresses in lower socio-economic households, socioeconomic status may appear to be the link when it is really about family relationships, parent-school engagement or social capital. Lamb and Ball (1999), Lyons (2006a) and Schneider, Swanson & Riegle-Crumb (1998) discuss parents’ educational attainment and expectations as significant in influencing student choice into STEM. Henderson and Berla (1994) argue that the link between parent and school is critical. Putnam (2001, 2004) found that community based social capital was a better indicator of improved educational outcomes, than socio-economic status. Grissmer et al (2000) argue that this occurs through “peer effects, quality of communication and trust among families in communities, the safety of neighbourhoods, and the presence of community institutions that support achievement” (pp. 17-18). Further research into this issue is required. Effects of family relationships on STEM participation could be linked to optimism building. Seligman (1995) describes how the actions of parents can increase or decrease optimism.

5.1.7.6 Student language background and ethnicity

Conflicting evidence emerges on the impact of language background. Students with an English language background performed significantly better in PISA 2006 than their peers from Non-English Speaking Backgrounds. More “students with a language background other than English (20% compared to 11% of English-speaking students) were not achieving proficiency level 2” (Thomson & De Bortoli, 2008b, p. 13). However, students from non-English speaking backgrounds have higher participation rates in advanced mathematics and physical science subjects (Ainley & Elsworth, 2003; Committee for the Review of Teaching and Teacher Education, 2003c; Lamb & Ball, 1999).

There has been considerable research in the U.S. in particular concerning the lack of participation of minority groups in STEM, and this is often associated with studies of women in STEM, as described in the gender section above. A particular concern in the U.S. is the low participation rates of black men in STEM courses. In the UK, Stagg, Laird and Taylor (2003) found significantly higher attitudinal levels towards scientists amongst middle years students of Asian background, compared to the general population. Elias, Jones & McWhinnie (2006), in a study based on the pipeline metaphor starting from the achievement of prerequisite sciences at GCSE level, found that Indian and Chinese students outperformed white students, while black Caribbean, Pakistani and Bangladeshi students performed less well. This pattern was repeated, with variation, through to final degree level, but there were
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interesting differences in the continuation of chemistry compared to physics, interpreted on the basis that chemistry was a pre requisite for medicine, a career outcome favoured by non-white students, particularly Asian students. Within STEM subjects, a bias with ethnic minority groups was found against the traditional areas of science — physical and biological sciences and mathematics — whereas ethnic minority groups were over represented in ICT and computer science. White students were more likely to continue with PhD studies in chemistry and physics than their equally well-performing ethnic minority counterparts, who undertook further study in different areas. From this, it seems that subject choice and career aspiration are strongly culturally related, presumably through the influence of parental and perhaps peer expectations.

5.1.7.7 School sector

School sector in Australia has an impact on participation rates, with students attending Government schools far more likely to participate in VETiS and Technology subjects than their peers in Catholic and non-Government schools, while students in non-Government schools have higher participation rates in Biology than do their peers in Government schools (Ainley & Elsworth, 2003; Dalley-Trim et al., 2007).

While a number of characteristics, contexts and attitude traits correlate with success and perseverance in STEM education, it is evident that not all people who continue in STEM experience continuity, neither do they fit an ideal-type, and indeed many persist despite numerous difficulties and impediments (Johnson, 2007). Perseverance flows from the facilitation of experiences that allow people to feel they personally belong in STEM, and through such experiences, to develop resilience to persist despite impediments. Encouraging students to engage in STEM must necessarily tackle the issue on a number of levels, including providing information, assisting students to make considered decisions based on this information, and importantly, extending students’ horizons by providing access to positive images of what it is like to belong in STEM. Encouraging participation on a number of levels, but in particular at this personal level, helps build student resilience, and opens up options if a pathway becomes blocked.

5.2 Teachers and teaching

The key to student choices and learning outcomes in mathematics and science is widely acknowledged to be quality teachers, who are knowledgeable and committed to student learning and engagement, passionate about their subject, capable of flexible approaches to teaching and learning, and who have faith in their students (COSERPUP, 2005; DEST, 2003; Goodrum et al., 2001; High Level Group on Human Resources for Science and Technology, 2004; P. W. Hill & Crevola, 1997). Part of the issue in Australian education, as elsewhere, is a looming shortfall in the supply of science and mathematics teachers. For science this is the case especially in the physical sciences in rural areas. Given that the quality of teaching is severely compromised by a teacher’s poor understanding of subject content, and
that this has a significant impact on student attitudes and choices, the strategy of filling school vacancies with under-qualified teachers does not bode well for a system-wide prioritisation of STEM (see Figure 4.3). As Dr Lawrence Ingvarson from ACER observes:

A deep understanding frees you up to use good pedagogy, to discuss ideas, to relax, to open up the discussion, to throw away the textbook and to throw away the work sheets because you are interested, you understand the ideas and you know how to promote those ideas and that discussion (Senate Standing Committee on Employment Workplace Relations and Education, 2007, p. 111).

Though the picture is not all negative. Early signs from the evaluations of four Higher Education Funding Council for England (HEFCE)-funded pilots to improve Higher Education enrolments in physics, chemistry, engineering and mathematics suggest that interventions which encourage more students to apply for STEM courses, coupled with changing the way these courses are taught, increases the number of students attracted to these fields, and improves student retention.\(^6\) Similarly, there is some indication that marketing campaigns and branding strategies designed to increase student numbers in teacher training courses in the UK, Singapore, Boston and Chicago have likewise been effective (Barber & Mourshed, 2007).

There is some evidence to indicate that expensive and widespread changes in curriculum, assessment regimes and standards are not always followed by desired changes in teacher pedagogy and practice (Cohen & Hill, 2000; Kleinhenz, Ingvarson, & Chadbourne, 2001; Stillman, 2004b). Indeed, teacher involvement and consultation in the development of education initiatives is all too often neglected, and a resulting gap between the practiced teacher behaviour and desired teacher behaviour emerges. This is notable in the UK with the implementation of the GCSE and KS3 curricula, which were developed to further connect ‘school science’ to contemporary science. The changes to the curriculum also required a change in teaching and assessment practice that many teachers and examiners did not find straightforward.\(^6\) The same types of problems were encountered in the implementation of the Victorian Certificate of Education Mathematics Study Design (Stillman, 2004b). Highlighting a gap between theory and practice, Walls (2007) shows that changes in the culture of mathematics teaching advocated by educational researchers and curriculum designers — emphasising active learning and problem solving — are not reflected in primary students’ drawings of themselves ‘doing’ mathematics, nor in secondary students descriptions of their typical maths lessons, which depict static situations and desk work. Thus, where teachers are the crucial link between policy and practice, a significant amount of attention must be paid to teacher professional learning.

\(^6\) See [http://www.hefce.ac.uk/aboutus/sis/stemproj/](http://www.hefce.ac.uk/aboutus/sis/stemproj/)

5.2.1 Who is teaching science?

A number of reports have focused on this issue for teachers of science (DEST, 2003; Harris et al., 2005). The findings include:

- The number of students in secondary teacher education courses undertaking physics and chemistry subjects declined by 62% and 37% respectively between 1992 and 2000 (DEST, 2002, p. 11).

- Only a minority of junior to middle school teachers of science had studied physics beyond first year level (Harris, 2006; Harris et al., 2005).

- The percentage of schools that report experiencing difficulty in adequately staffing physics and chemistry classes, is 40% and 33% respectively (Harris, 2006).

- Low levels of science teaching and learning are biting particularly in non-metropolitan areas, where, in a recent national survey (Lyons, Cooksey, Panizzon, Parnell, & Pegg, 2006), schools in regional areas and those in remote areas are respectively twice and four times more likely to report it was ‘very difficult’ to fill vacant teaching positions in science, ICT and mathematics than those in urban areas.

- The shortage of teachers in the physical sciences will worsen, given that existing teachers tend to be in the older teaching demographic. Half of science teachers under 35 years of age have predominantly biology backgrounds, and have studied no physics at university (Harris, 2006)

- There are high levels of disillusionment among current science teachers with work conditions and negative student attitudes. These are associated with low levels of expectation of staying in teaching in the longer term.

The evident shortage of science teachers will make school science reform in STEM difficult, given the importance of having trained and enthusiastic teachers of science leading innovative science teaching practices, especially in the physical sciences. Attracting talented students into science teaching is a serious challenge.

Darby (2008), based on a classroom video study of science and mathematics teachers teaching across these disciplines, makes the point that effective teaching involves not only subject matter knowledge, but aesthetic understandings. She explores beliefs and experiences of what it means for a teacher to: be compelled by and passionate about the subject and students’ engagement; have a coherent and unified sense of what the subject is about and how to bring it to life for students; and be transformed by what he/she knows in such a way as to personally and professionally identify with the subject. Being an inspiring teacher involves being steeped in the discipline and its teaching beyond baseline knowledge, and this has significant implications for teachers being required to teach ‘out of field,’ as so many are, and will increasingly be required to do.
Part of the current and looming crisis in science teacher supply is a product of economic circumstances. It is also part of a downward spiral, stemming from the lack of engagement of students in STEM pathways. The lack of students taking STEM pathways impacts on the quality of teachers entering the profession. The practice of asking educators to teach in areas in which they do not have subject expertise, will make any reform process very difficult.

5.2.2 Who is teaching mathematics?

Similar findings to those for science (along with ICT and language) teachers have been reported for mathematics teachers. Mathematics teachers are aging. There is a declining pool of graduates to draw from to enlist new teachers of mathematics, and increasing competition for mathematics graduate from other STEM areas. This has led to mathematics being taught by unqualified and poorly qualified teachers and arguably a consequent decline in student motivation, achievement and numbers studying higher level mathematics in secondary and tertiary education (Australian Academy of Sciences, 2006; Thomas, 2000).

Although over 91% of secondary Mathematics teachers have tertiary qualifications in Education, over a fifth had not studied Mathematics beyond first year, and over 8% no university mathematics at all, and 16% had not studied any Mathematics teaching methods (Harris & Jensz, 2006). There appears to be variation between states; thus in Queensland:

The 2006 Teacher Qualifications Survey of all permanently employed state school teachers (approximately 32,500) found that approximately 30 per cent of Senior Mathematics A and Years 8 to 10 mathematics teachers indicated they lack subject-specific qualifications. Approximately 15 per cent of teachers of these subjects indicated they are neither qualified nor have significant experience (Queensland Department of Education Training and the Arts, 2007).

In international comparisons Australia has a high proportion of mathematics teachers who have studied mathematics teaching methods but in terms of mathematics qualifications we are significantly poorer than Singapore and Japan but better than such countries as England, United States and New Zealand. The level of qualifications of mathematics teachers compared favourably with IT teachers and unfavourably with science teachers (Figure 5.5). These figures are significantly worse in rural and low socio-economic schools (Harris et al., 2005; Sue Helme & Lamb, 2007) and Independent and Catholic schools tend to have better qualified Mathematics teachers (see Figure 5.5).
Figure 5.5: Highest qualification held by Year 12 mathematics, science and technology teachers by school sector.

<table>
<thead>
<tr>
<th>Highest Qualification</th>
<th>Government</th>
<th></th>
<th>Catholic</th>
<th></th>
<th>Independent</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>≥3rd Year University</td>
<td>62</td>
<td>77</td>
<td>40</td>
<td>78</td>
<td>86</td>
<td>60</td>
</tr>
<tr>
<td>≥2nd Year University</td>
<td>75</td>
<td>87</td>
<td>47</td>
<td>84</td>
<td>92</td>
<td>63</td>
</tr>
<tr>
<td>Other post-school</td>
<td>20</td>
<td>12</td>
<td>30</td>
<td>11</td>
<td>6</td>
<td>23</td>
</tr>
<tr>
<td>School or none</td>
<td>5</td>
<td>2</td>
<td>23</td>
<td>5</td>
<td>2</td>
<td>15</td>
</tr>
</tbody>
</table>

Source: Committee for the Review of Teaching and Teacher Education (2003). Australia’s Teachers

Two fifths of teachers are dissatisfied with their preparation for teaching while almost all (98%) valued continuing professional development (Harris & Jensz, 2006).

Three quarters of schools report difficulty recruiting qualified Mathematics teachers and this is perceived by departmental heads and principals as an increasing problem with many Mathematics teaching staff due to retire; fewer than half of teachers were confident that they would be teaching in five years and one sixth were definite that they would leave teaching within five years. The majority of these teachers were experienced. A large number of early career teachers were uncertain of their long term future in teaching (Harris & Jensz, 2006). Rural and low socioeconomic schools had the greatest difficulty filling vacancies and obtaining qualified relief teachers (see Figure 5.6).
Mathematics teachers are an aging population. The age profiles of Mathematics teachers in a sample survey of Government secondary schools in Victoria shows a significant shift in the peak age group from 40–44 years in 1995 to 50–54 years in 2006 (see Figure 5.7). This pattern is mirrored in other states (NSW Audit Office, 2008; WA DET, 2007) and many other nations (OECD, 2005b). Queensland has younger mathematics teachers with only 27.9% of mathematics teachers in Queensland aged above 50 (Queensland Department of Education Training and the Arts, 2007), compared with 37.8% of mathematics teachers aged above 50 nationally (Harris & Jensz, 2006).
For Mathematics the second peak in the 25–29 year olds is much smaller than that for other subjects, such as Physical Education and Science (Teacher Supply and Demand Reference Group, 2006). It is also notable that the crisis is being ameliorated by Mathematics teachers leaving the profession later over the past ten years. However this cannot continue for ever:

Even if this generation of teachers could be persuaded to stay on until they reached the retirement age of 65, this would only alleviate problems in the shorter term (Watt, Richardson, & Pietsch, 2007, p. 797).

The pool of students who are studying mathematics both in senior secondary and at university has been steadily declining by about 20% over the past decade as is documented in Sections 2.2.2 and 2.2.3 and this has an effect not only on the supply of Mathematics teachers but also many other subjects, notably Physics. There are longstanding concerns about Mathematics teachers leaving teaching for industry (Australian Academy of Sciences, 2006; OECD, 2005b) and moving from government to independent schools because of higher wages (Committee for the Review of Teaching and Teacher Education, 2003c). Evidence for this assertion comes from Queensland data where the attrition rates for mathematics and science teachers (6% per annum) is higher than the general teaching population (4%) (Queensland Department of Education Training and the Arts, 2007).

Although Australian mathematics teachers compare favourably in international comparisons, the aging population together with the declining participation in advanced mathematics at upper secondary levels is of great concern. Further, there is need to address the supply of high quality mathematics teachers in rural and low-socioeconomic schools.
5.2.3 Teacher training and professional learning

The findings of this review make it clear that the quality of teachers and their classroom practice is a key factor in engaging students in STEM, and that the issue is largely one of pedagogies that support interest and engagement, arguably more so than curriculum content. Any significant initiative to support changes in classroom pedagogy will require carefully planned support for teachers. Many studies have shown that short-term professional development (PD) events are ineffective in promoting significant change in teacher and school practices (Hoban, 1992). Many writers (e.g. Hall & Hord, 2001; Hargreaves, 1994) have emphasised that change in professional practice requires of teachers that they ground new ideas in their own personal experience. Joyce and Showers (1995) argue for the need to situate professional development within the school context. Contemporary large-scale reform projects in a number of countries have incorporated these principles (Beeth et al., 2003; Parchmann et al., 2006).

Barber and Mourshed (2007) in a comparative report of school systems internationally, place most emphasis on the need to improve and maintain quality instruction at the classroom level, and emphasise issues of teacher recruitment (and status), teacher training, and professional learning support, as the key factors. They identify a focus on individual practice, building of practical skills, support by instructional leaders in authentic settings, enabling teachers to learn from each other, and building leadership capability in schools focused on classroom learning.

A number of Australian large-scale projects have focused on pedagogy (for instance Productive Pedagogies (Queensland Department of Education Training and the Arts, 2004) and School Innovation in Science (SIS) (Victorian Department of Education and Training, 2003)). The experience of SIS has demonstrated that pedagogical change requires considerable support in schools. In SIS, as with other system-wide reform projects involving local control and attention to pedagogy, there was a significant sense of ownership of the reform, and there was significant change in classroom practice. SIS has spawned a wide variety of initiatives, and the school and teacher change model (Tytler, 2007b, in press) became very well regarded in Victoria and was adapted to other projects (Tytler, 2004, 2005; Victorian Department of Education and Training (DE&T), 2003, 2004).

The CASSP trial project (Goodrum, 2006) on which the national Science by Doing initiative is based, and Primary Connections (Australian Academy of Sciences, 2005; Hackling, 2008) both have a professional learning model sitting within them, involving a participative inquiry in professional learning element. The Primary Connections initiative is attempting to accommodate both these models, developing teacher unit materials to exemplify inquiry approaches within a conceptual change model, and also developing a set of pedagogical principles related to SIS, and a PD module supporting schools to take ownership of the way they use the program. This degree of flexibility has already paid dividends, with trial teachers introducing significant modifications to the learning sequences, adding and subtracting to adapt the units to local conditions. Such flexibility is needed if teachers are to be
encouraged to be responsive to their students needs, and to link science with the local context and community.

In a submission to the Victorian Inquiry into professional learning of teachers (Victorian Parliament Education and Training Committee, 2006), the Mathematics Education Research Group of Australia (MERGA, 2007) identified a number of features of effective professional learning provision for mathematics teachers, which are consistent with the principles above. These include opportunities for teacher reflection, regular release time to work in teams on planning and reflecting on school specific tasks with the guidance of a university based expert, the use of action learning cycles over a period of time to refine these tasks, and support and leadership within the school.

### 5.3 Mathematics and science

Both school mathematics and school science are critically important in preparing students for adult lives interacting with STEM or working as STEM professionals, and engaging them both conceptually and aesthetically (Darby, 2008; Zembylas, 2005) with science and mathematics. The review has treated mathematics and science literature separately in Sections 3 and 4, but brought together the themes from both areas in the discussion in Section 5, and the Section 6 themes and findings will also integrate these themes and literatures.

There are many themes the review has uncovered that relate to both school science and mathematics, such as learning and identity, gendered responses, self efficacy, the need for conceptual challenge, and the usefulness of real contexts in supporting meaningful learning. There is a need for both school subjects to reflect the way these disciplines are represented and practised in society more generally. For school science, and particularly physical science, and school mathematics, there are current and looming shortages of teachers and an increasing incidence of out-of-field teaching, and at primary school level there are issues concerning the confidence and competence of teachers to support deep intellectual engagement during the learning of science and mathematics.

However, there are substantial differences between the subjects that warrant some discussion at this point. First, developing student understanding of science importantly involves closing the gap between students’ prior conceptions of science phenomena developed perceptually and through everyday language, and the often counter-intuitive concepts of science, whereas developing understandings of mathematics is based upon building problem solving capabilities such that misunderstandings arising from rule based pedagogies are limited. Second, mathematics is quite differently placed compared to science, in the primary school curriculum. It is considered a core subject more so than science and is much more strongly represented in national priority documents (as numeracy alongside literacy), in curriculum time, and in teachers’ and students’ minds as ‘core business’. In a project explicitly comparing mathematics and science disciplinary practices in the Middle Years (Tytler, Groves et al., 2007), differences between pedagogical beliefs of mathematics and science teachers were explored. That analysis is ongoing, but the findings indicate minimal differences at the primary school level but
more substantial differences at the secondary level. Groves (2008) describes how science teachers, based on an interview instrument exploring their pedagogies, represent significantly higher than mathematics teachers (at the 0.001 level) the components *a rich view of practice in the discipline, collaborative work, catering to student lives and interests, investigation and problem solving, and the interweaving of concrete and abstract*. Darby (2007) found that while both mathematics and science teachers were strongly committed to making the subject relevant, how they threaded this relevance into their teaching differed. An analysis of the teachers’ use of stories, or “meaning making,” demonstrated a more frequent use of stories representing the human side of the subject in science than in mathematics. Darby (2008b) contrasted what teachers considered to be central pillars to school mathematics and science, describing the greater reliance on concrete and phenomenon based activities in science teaching, and the greater attention given in mathematics to the support of individual students in ensuring that the sequential conceptual content is mastered. In a survey of student attitudes to science and mathematics, primary school students rated mathematics as significantly more useful, now and in the future, compared to science, but significantly less interesting or enjoyable (Groves, 2008).

In school the subject of mathematics is seen by many teachers and curriculum designers as much more structured and sequential than science (Siskin, 1994), such that students need to master one level before moving to the next, with absence or failure having major implications for ongoing participation. Implicit in the emphasis on learning mathematics through problem solving, is the recognition that school mathematics does not need to be structured so rigidly. Even for problem solving situations, however, students need sufficient background knowledge to be able to begin to explore. Science, on the other hand, is more topic based and less strictly sequential, with progression sequences through concepts less tightly defined. These differences are reflected in the literatures surrounding learning and engagement in the subjects, with the mathematics literature on engagement emphasising intellectual and affective engagement accompanying conceptual learning, providing tasks that address individual differences and use authentic contexts, and the importance of resilience and self efficacy in taking the risks associated with problem solving activity. The science literature on conceptual learning is vast, but the literature on engagement, strongly represented in this review, tends to focus on the importance of context and personal relevance, critiquing the restricted pedagogies used in science classrooms generally. In science as for mathematics, ultimately the interest resides in an appreciation of the conceptual explanations and structures of the discipline and their power in making sense of the world. For science, however, this pathway involves, more strongly than for mathematics, helping students make links with their experiences of the world and of the impacts of science on our lives. For mathematics, while engagement involves using mathematics as a tool for making sense of their world, there is also a strong emphasis also on overcoming challenges associated with building new conceptual understandings that can be associated with the mathematics itself and separate from real world contexts.

Darby (2008a) contrasts different teachers’ understanding of the mathematics and science subjects at an aesthetic level. She describes how their teaching is impacted not only by their knowledge of content and how to teach it, but also their appreciations for what the subject offers themselves and their
students, and how they see themselves in relation to the subject. This was particularly evident for teachers who taught subjects for which they had limited appreciation, or aesthetic understanding, which can be the case for a mathematics teacher teaching science, or a biology teacher teaching physics. Corrigan and Gunstone (2007) discuss the different values operating in mathematics compared to science. While there are significant commonalities, for instance around the commitment to rationalism, and aspects of the sense of mystery valued in these disciplines, the empiricism of science - the way ideas derive from observation and experimentation and the values pertaining to precision, coherence, measurability and parsimony that flow from this, are not as strongly represented in the mathematics although they do relate to mathematical modelling. The treating of ideas as objects, strong in mathematics, does not translate to science. The nature of science is commonly taught, and the values in relation to social uses of science made explicit, whereas in mathematics the values are implicit, and the nature of mathematics rarely discussed. Corrigan and Gunstone (2007) point out the potential difficulties for students in appreciating differences in the value systems of the two subjects. It seems plausible that this difficulty could also apply to teachers coming to mathematics or science from other discipline bases.

These dimensions of the subjects - values and aesthetics - pose potentially significant issues for teachers of mathematics or science who are not trained in the subject. This is perhaps particularly pertinent at the grade levels in which students’ identity is significantly interacting with their view of the subject. It is clear from the review that it is not only the conceptual content that must be represented to capture students’ interest and stimulate their conceptual engagement. There are significant aspects of the contemporary relevance and practice of mathematics and science, and particular ways of responding to phenomena and thinking through these disciplines that frame students’ commitments. Effective teaching of mathematics and science presume substantial teacher knowledge and commitment to both the subject matter and the way it is appreciated and learnt.

The multiple issues discussed in this review, concerning pedagogy, the arrangement of content, context, resilience and self efficacy, concern both mathematics and science teaching and learning, but the emphasis is different given the different nature of these subjects and the way they are structured. It is our view that these differences relate strongly to the traditions that have been built up for the school subjects of mathematics and science, and these are only partly determined by the nature of the disciplines of mathematics and science themselves. In a curriculum that was more focused on thinking mathematically and scientifically, and on the way these disciplines are practised, then problem solving and investigating, and problem based learning with inter-disciplinary features, would be featured more strongly. In this circumstance, the differences between science and mathematics learning would diminish, although by no means disappear.

We would thus argue that the findings and themes that are uncovered in the review, if they were to be acted on to increase engagement of students with mathematics and science, would also have the effect of bringing the practices in the two subjects more closely together.
5.4 Assessment in school science and mathematics

Recently, there has been considerable focus on the need to support teachers in formative assessment approaches. This has been occasioned by a significant review of the assessment literature by Black and Wiliam (1998a, 1998b) which showed that formative assessment, and particularly the quality and timing of student feedback, make a significant difference to student learning outcomes. Following that review, there has been significant activity in the UK, working with science teachers on approaches to formative assessment (Black, Harrison, Lee, Marshall, & Wiliam, 2004; Black, Wiliam, Lee, & Harrison, 2004), and in New Zealand in the area of science education (Bell & Cowie, 1999, 2001). A key aspect of the UK work has been the development of student autonomy in learning, using peer assessment approaches, and working with teachers to gradually feel more comfortable in releasing control of the learning process. Such approaches are consistent with the pedagogical changes called for in middle years science and mathematics classrooms.

Assessment is a key element in any mooted curriculum change. The history of education reform is littered with examples of summative assessment regimes failing to support the intention of the innovation. Hart (2002) describes the interaction between assessment demands and curriculum policy that subverted an attempt at a context-based physics curriculum. Calls for changes to the curriculum, and to classroom practices, imply changes to the purposes of school science. To support these it will be necessary to have a parallel development of approaches to assessment that reflect these wider purposes. Assessment of student knowledge of contemporary science practices, for example, or assessment of inquiry skills or the nature of STEM work, or disposition to engage in investigation and imaginative design, may be important projects to support changed teaching approaches that encourage students into STEM pathways.

In Australia, there is a move towards a national curriculum and towards greater accountability of the education system nationally, through benchmarking processes. In mathematics, this report has described the negative effects of assessment that focuses on low level content coverage and fails to support the type of challenge and interest that engages students in thinking mathematically. In England, the advent of a National Curriculum which prescribed a comprehensive content program, and supported this with high stakes testing, was held to have a restricting effect on classroom strategies. An early report on the effect of the National Curriculum in Science (Russell, Qualter, & McGuigan, 1995) found that enthusiastic teachers of primary school science had become more teacher centred in their approach, had restricted their range of classroom strategies, and felt de-professionalised. A more general, longitudinal review of the classroom effects of the National Curriculum implementation was undertaken by Hacker and Rowe (1997; 1998), based on classroom observations. They found that, compared to the situation before the national curriculum was introduced, classrooms were more teacher centred with a variety of interactions (pupil-pupil, or involvement in experimental work) decreasing in number. They also found an increase in behaviours associated with acquiring, recalling and confirming facts, and a decrease in behaviours associated with underlying concepts and principles, problem solving, experimental procedures, or interpreting and inferring from observations. These are precisely
the behaviours associated with intellectual challenge and interest, advocated for increasing student engagement with science and mathematics.

Au (2007) undertook a meta synthesis of 49 studies of the effects of high stakes testing. He found that such high stakes testing regimes overwhelmingly led to a contraction of the content of the curriculum, led to an increase in the fragmentation of the knowledge into bits that were specifically learnt for the test, and led to an increase in teacher centred pedagogies. However:

Another significant finding of this study is that, in a minority of cases, high-stakes tests have led to increases in student-centered pedagogy and increases in content knowledge integration. Combined, these findings indicate that high-stakes testing exerts significant amounts of control over the content, knowledge forms, and pedagogies at the classroom level (Au, 2007, p. 264).

This minority of studies involved testing that introduced new and more complex literacy requirements, that encouraged teachers to focus on higher level thinking in their classrooms. Thus, we can see that testing can be an effective policy instrument for moving practice in desired directions, but more often than not the opportunity is squandered because of a narrow range of assessment approaches and an emphasis on low level, fragmented content.

5.5 Career guidance

5.5.1 Career expectations and advice

Stereotypes about STEM careers tend to restrict students’ understanding of their own career pathways and options. A brief consideration of student career decision-making is warranted in that Australia’s future workforce is fed by young people, and their decisions and resilience to succeed when faced with setbacks will not only have an impact on their personal pathways, but will also in part forge the shape of the Australian workforce. In order to make considered decisions, students need access to timely and accurate information about careers and workforce demand, they need the ability to use this information for personal decision-making and, importantly, the capacity to imagine their future-selves in the shoes of STEM-professionals. Students need to be made aware of careers in, and careers from science and of the flexibility offered by STEM subjects and courses. A thorough analysis of career guidance service delivery in Australia is beyond the scope of this report, but a number of observations are worth making about young peoples’ understanding of themselves, their school contexts, their futures, the workforce and their friendship groups, and how this understanding can impact upon the successful delivery of career guidance (DEST, 2002; Wendy Patton, 2005).  

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17 For a detailed outline of Australia’s career guidance services and recent initiatives, see DEST (2002) *OECD Review*; Patton (2005) “Coming of Age?”
Students actively pursue and take an interest in planning their futures.

Career planning and decision-making can be an overwhelming task, and young people need support to successfully negotiate aspirational career pathways.

Students attending schools with better developed support systems to assist with career decision-making are less likely to look elsewhere for advice.

A survey conducted in the UK for the Engineering Council by the National Foundation for Educational Research using a questionnaire survey of a random sample of 1011 students provides some insights into the factors influencing student choices at age 14 (Engineering and Technology Board, 2005a).

Students were asked about their interest in studying four main subject areas – English (37%), mathematics (36%), science (37%) and ICT (42%) and the figures in brackets show the percentage of students who say that they really want to study this subject. When added to the number who say that they are ‘not keen but it is important’ the figures are English (94%), mathematics (94%), science (96%) and ICT (77%).

Asked about careers, 68% said that they were interested in at least one area of SET careers. 41% of all students expressed interest in a career in technology which was more popular than careers in science or engineering (both 28%).

The report divided its sample into high achievers and low achievers using a proxy measure of self-reports about the number of GCSE exam passes they were anticipating at age 16. The survey found that high attainers, those expecting to stay on in higher education and those with a higher socio-economic status, had a greater desire to study science, mathematics and English. There were also significant gender differences with more boys than girls demonstrating a real interest in studying mathematics, science and ICT. Girls’ interest was predominantly instrumental reflecting that these subjects were seen as being important to life beyond school. This research indicates that young peoples’ career aspirations are reflected in their school subject choice, and in the strength of their pursuit of educational pathways that will assist them to fulfill these aspirations.18

Students were then asked a number of questions about what they thought people working in science, engineering and technology do (Figure 5.8).

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18 Beavis (2003) finds a particularly strong correlation between ‘investigative’ interests — those most usually associated with a STEM orientation — and the motivation to pursue this interest through study and work.
These responses give an interesting insight into student perceptions of these careers and some misconceptions. Only slightly more than a third see engineers as engaged in design or undertaking work that will help to save lives. Rather, they have a very old-fashioned conception that engineering is about working with machinery and more than half think that involves working with oils/chemicals. Technology in contrast is seen by the overwhelming majority as being about design with over two thirds thinking that it involves developing new ideas. Over half see the working environment as being in an office – something which might be seen as a more pleasant working environment. In terms of young people’s aspirations to be engaged in something where they can make an innovative and meaningful contribution, it is apparent that the opportunities offered by technology are more appealing which might explain why more of them express interest in a career in technology and why many undergraduate courses have now incorporated the word ‘technology’ in their title e.g. music technology, communications technology. In this way, it is evident that the choices that students make in forming and pursuing career prospects are influenced by a wide variety of factors, including the values that they hold about those careers. These findings can be linked to the assertions of Schreiner (2006) and Schreiner and Sjoberg (2007) that young people need to meaningfully contribute to society.

Students were also asked about the types of conditions they would prefer when they went into a job. Two-thirds of the students said they wanted work that gave them the opportunity to make decisions and allowed them to use their communication skills. More than half said they wanted to have professional
work and to work with their hands. These responses reflect the kind of work undertaken at consultant or management level which could be consistent with many careers in science, engineering and technology. However, only 15% of students said they wanted to deal with lots of paper work. More worryingly for engineering is that only 30% wanted to be involved in designing bridges or cars and only 33% wanted to work with machinery.

Undertaking a factor analysis, the profile of students who were interested in a career in science was that they were:

- higher achievers (those who identified themselves as likely to achieve five or more GCSE\(^9\) grades A*-C)
- from the upper end of the socio-economic scale (three or more bookcases in the home)
- committed to staying on in HE
- attracted to working in an office
- attracted to careers that involved caring for others.

Students interested in a career in technology were:

- boys
- higher achievers
- at the lower end of the socio-economic scale (very few books in the home)
- attracted to practical work
- not attracted to work that involved caring for others.

The authors caution that students of this age still have up to 7 years of full-time education and a limited knowledge of careers. Nevertheless, it does raise the policy question of whether it might be best for any country worried about the future supply of STEM professionals to specifically target these two groups, and adopt policies that acknowledge the variety of orientations and interests of youth in schools.

### 5.5.2 Knowledge of careers

Schools can make a difference to students’ decision-making processes, and promote good choices by supporting students and equipping them with critical skills. The more effective a school’s supportive

\(^9\) General Certificate of Education which is the national examination taken at age 16.
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structures, the less likely students are to seek external advice (Blenkinsop et al., 2006). The potential impact of effective support structures is wide-ranging, as the formal provision of good career advice has the potential to offset the negative impact of cultural myths and stereotypes that impede students’ decision-making.

In the previously described UK study of how young people make choices at age 14 and 16 (Blenkinsop et al., 2006), 56% of their sample believed that the way jobs and careers had been portrayed in the media had influenced their choice. However, the two main sources of information were ‘someone who works in that job or career’ (72%) or ‘a school careers teacher’ (67%). Nearly three quarters (72%) wanted information from somebody who works in the field and such contact is highly valued (Stagg, 2007). Indeed the conclusion drawn by a recent UK report on careers in science is that for students

People, their lives, and the work they do are the richest and most respected resource for learning about careers. Whilst a proportion of young people are attracted to science and technology for itself, many are interested first in the people (role models etc) (Stagg, 2007, p. 4).

This report, based on a survey of science teachers, students, careers teaches and others, found that ‘students have a narrow and limited view of ‘science careers’, and the career routes available to people with interest or aptitude in science’. Whilst medicine and science as featured on television (e.g. forensic science) are well recognised, other careers either in or from science (careers from science are those for which science qualifications confer favor but are not centrally in practicing science) are not. Moreover, much of the information that they do receive tends to focus on their educational progression – the next step up the educational ladder with the university degree as the dominant focus. Clearly what is needed is not so much a program of persuading students of the value of scientific careers as much as one of simply opening up the windows of possibility.

The policy implication is clearly that better information about the kind of people working in STEM, in a form that is readily assimilable, would be helpful and well-received. In the UK, a new website ‘Careers from Science’ is being developed which will include video clips of a range of STEM professionals talking about the work that they do.

When asked, however, which sources of information were very useful or useful, 72% said subject teachers, 61% adults working in specific jobs and careers and 50% websites. This finding would suggest that websites are not the dominant medium for communicating information about future careers but, nevertheless, significant and, as they improve, potentially more so. However, research has also shown that few young people, particularly at age 14, made the link between careers education and guidance activities and the actual personal decisions they were making.

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20 See http://www.sciencecouncil.org/projects.php for further information

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The reliance on teachers of science is somewhat worrying given some UK research that found that teachers of science did not perceive themselves as a source of career information, regarding it as the responsibility of the careers teacher (Munro & Elsom, 2000). In a survey of Year 11 students in NSW, Haeusler and Kay (1997) found that despite the fact that teachers are often classed by senior secondary students as more influential than any other group—including parents, other adults and peers—they nevertheless have a very limited influence on student subject selection. Haeusler and Kay observe that providing formal careers advice to students in the junior years may be an effective way to equip them with the necessary information and techniques for subject selection and future career planning. Raison (2006) found from a survey of senior high schools students in rural and urban NSW that science teachers were the most trusted source of SET career information for students enrolled in science subjects (but not for those students not enrolled in science subjects). Moreover, the compulsory nature of the 14-16 year old courses in science means that there is little incentive for teachers to ‘sell science’. Indeed some recent research conducted in the UK found that teachers felt that they were not well-informed about careers in science (Stagg, 2007). If science teachers are looking to careers advisors as a source of information some concern must arise from the fact that this research found that the majority of the careers advisers (from a sample of 155) were graduates with a humanities or social science background with only one in ten having a science degree, and then all in the biological sciences. These careers advisors were, however, concerned about the lack of interest in science and their low-level of awareness about the links between science and future employment. As articulated by the Head of Careers at Imperial College London, the three qualifications that make any individual most employable are the advanced study of mathematics, physics and another science (Simpson, 2004).

The degree of influence parents have on student subject selection and career aspirations is inconsistently reported. Only 38% of parents were seen as useful sources of information but a review of research on the influences on student career choice found that parental support and interest was important to the success of any specific teaching or interventions about careers (Moon, Lilley, Morgan, Gray, & Kreczowicka, 2004). The Engineering and Technology Board (2005b) commissioned a focus group study of parents’ perceptions of SET careers in 2005. The general picture emerging from this was that parents felt the sources of information that young people had access to were much more diverse than in their own days. And, given the insecurity associated with their future employment, it made more sense for them to study the subjects that they were interested in. The wisdom of entering a career in engineering, in particular, was questioned, given what was perceived as the decimation of manufacturing industry in the UK. This was particularly true of parents of a higher socio-economic status. Parents themselves did not feel at all well-informed about SET related careers.

21 Alloway et al., (2004) report that teachers, students and career advisers often see a strong parental influence on student career choice, but that this influential role is not generally acknowledged by parents. Bedson and Perkins (2006) reveal that young people often discuss their options with parents when considering what they will do after leaving school, whereas Haeusler and Kay (1997) review much literature that finds parents have almost no impact on students’ school subject selections, a crucial step in much career planning.
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However, for policy makers, an important finding from research on how young people at age 14 and 16 make choices is that ‘when students felt supported in decision-making by the school they were more influenced by school factors—such as individual talks with teachers and the careers education and guidance provision—and less reliant on external factors such as friends and family’ (Blenkensop et al., 2006). A number of directions are implied in these findings, ranging from asking teachers of science to give a greater priority to discussing careers in and from science; to taking students on trips where they can meet different people using science in their work; and generally raising students knowledge of the possibilities with STEM would seem to be important initiatives that could be taken by the national and state governments. To put it in a more prosaic fashion – how can a child aspire to what they have never seen, or how can they go where they have never been?

Students in Australia are not always getting the right information early enough to begin to make informed decisions about their future careers. This information needs to be targeted early in their schooling life, since career planning for many students commences early. Lord et al. (2006) identify primary school as a critical phase in developing attitudes, and in interviews conducted by Alloway et al. (2004), early years of high school were identified by respondents as a critical phase. This is consistent with much of the research described in this review concerning the point of choice.

Further, the career advice needs to be more responsive to changing workforce realities. There is evidence of a disconnect between Australian students’ career aspirations, and projections of workforce opportunity in the short and medium term, and between students’ career aspirations, and their understanding of the steps that need to be taken to get there. Access to the right sort of knowledge is crucial for successful career decision-making. A study conducted by Alloway et al. (2004) found that “Career-related information used by Career Advisers, students and parents was sourced from diverse places including government publications, school information events, internet sites and university Open Days.” This diversity of sources needs to be reflected in the information flowing to students from an early age.

Work needs to be done on improving students’ knowledge of STEM careers. However, just as important as information about career paths, is the presentation of stories of people working in STEM and an understanding of who STEM workers are, and what STEM workers do. A number of focus groups conducted for the Young Visions Project, found not only that young people were interested in meeting people “in the world at the moment,” but also that they “particularly liked it when the speakers talked about the steps that they took to develop their career rather than focusing on the career itself. The students were very focused on how to get places rather than what the place actually was” (Stokes, Wierenga, & Wyn, 2003, p. 16). Alloway et al. (2004) identify varied levels of confidence in Australia in the support provided by career advisors, as well as varied levels of awareness and access to formal career advice, and find that student-centred approaches to career-advice are highly valued by students and parents. The question is one of role models and identity – young people need to be able to imagine themselves into these possible futures. Figure 5.9 illustrates how student interest in STEM is engaged, with interconnected influences such as student identity, teaching and classroom quality, and student knowledge of and exposure to positive images of STEM.
5.5.3 *Enrichment and enhancement initiatives*

As part of school STEM subjects, there is the opportunity to provide students with models of professionals working in contemporary STEM occupations. This can be embedded in curriculum materials or achieved by links being made to STEM professionals through excursions or incursions, web based explorations of new developments, curriculum modules designed to embed this sort of material, or school-community linked units of work. “Direct contact between students and people working in scientific jobs tends to be identified by the students themselves as the most effective way to learn about careers” (Stagg, 2007, p. 12).\(^\text{22}\)

There is evidence that student learning and engagement in STEM is enhanced by participation in enrichment activities such as excursions, visits by STEM practitioners, travelling shows, competitions such as mathematics and science Olympiads or engineering design challenges, family science and mathematics nights, science clubs and extension activities. There is a tradition among teachers of doing *special activities* outside the main curriculum to cope with the diversity of students and to allow for a

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\(^{22}\) The effectiveness of the Science and Engineering ambassadors program in the UK on students’ attitudes toward STEM careers has not yet been studied.
range of activities well beyond what can be provided in the classroom. Cripps Clark (2006) in a thesis exploring practical activities in primary science, using experienced science-enthusiastic teachers, found that enrichment activities were more prevalent than expected. Educators speak of these activities as authentic, and children speak of them as real (Cripps Clark, 2006). This study found that teachers sometimes coordinated activities generated outside the school, for example, solar challenge, Streamwatch, Weatherwatch, and rodent research. However, such activities require dedicated efforts by teachers and adequate resources, as there are systemic factors operating against their inclusion. In Munro and Elsoms’ (2000) study of post 16 choices in the UK, they found that teachers regularly complained that the curriculum was so scripted and crowded as to discourage the engagement in such activities. Yet enrichment activities are particularly important in providing a stimulating environment for engaging students in learning mathematics, science and technology.

The report from a forum ‘Science Education in Europe: Critical Reflections’ (J. Osborne & Dillon, 2008) makes the point that most of students’ waking lives are spent out of school and that their science (a similar point could be made about mathematics) learning occurs largely in informal settings. Figure 5.10 represents this graphically.

*Figure 5.10:* Lifelong and lifewide learning in science (and mathematics) — the relative opportunities for informal learning

There is a wealth of literature on learners’ experience of informal settings and museums (Dierking & Falk, 1994; Rennie, Feher, Dierking, & Falk, 2003). Museums themselves offer a rich variety of experiences, and an examination of their websites shows a wide range of STEM-related content, including contemporary and historical technologies, the wonder of science, people in science and science in everyday life. Organisations such as Questacon or state museums have fresh displays and interactive exhibits, and run travelling shows that venture into rural areas. The Victorian Gene Technology Access Centre, or the Synchrotron are designed, for example, to represent cutting edge science and technology, and often put students in contact with practising scientists as well as run short courses with teaching staff or provide professional development for teachers. There is no long term
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evaluation of these programs, but anecdotal, observational and questionnaire evidence generally shows considerable enthusiasm by students for the experience.

There have been a number of programs that have put scientists, or university STEM students into schools to work directly with students. The Victorian Government ran a Scientists in Schools program as part of the Science in Schools initiative from 2000-2003, in which scientists and engineers (often retired) would work with primary teachers to institute science activity based curriculum projects. These were generally held to be successful, depending on the person and their capabilities, and the capacity of the school to plan around their strengths. The Australian Scientists in Schools program (www.sciencetinschools.edu.au) has over 500 scientists working as partners with teachers, across the country, on a variety of projects. The model is one of equal partnership, aimed at motivating students, and providing teachers with professional learning opportunities with respect to contemporary science practice. The project has been evaluated and preliminary reports are very positive.

Students and teachers derive knowledge on STEM at work and gain access to role models through partnerships between schools and industry or community organisations. School projects developed through partnership focus on local issues or research questions, and sometimes have students working with scientists, engineers or mathematicians on genuine problems. The Australian School Innovation in Science, Technology and Mathematics (ASISTM) project involved partnerships between clusters of schools, scientific and industrial organisations, universities, and government organisations, through which innovative curriculum experiences for students were developed. In a study of ASISTM, Tytler, Symington, Smith and Rodrigues (2007) developed an innovation framework to interpret these projects, pointing out that the practices and ideas developed were in alignment with the open pedagogies and focus on contemporary practice advocated in middle years writing. The technology projects were notable for the opportunity they offered for schools to access expensive and contemporary technologies, for instance for on-line design projects. There were a number of projects which focused specifically on alerting students to career opportunities in STEM in their local regions. In all of the projects studied, there were teachers who derived significant professional learning from the experience of working with scientists and other professionals, and many who were significantly rejuvenated in their enthusiasm for teaching. Another recent example is the STELR project (Managed by the Academy for Technological Sciences and Engineering (ATSE) and supported by the Australian Academy of Science and the Victorian DEECD), currently in pilot phase, which alerts Year 10 students to research and development, and professionals working in the renewable energies area. This might be by web searching for local industries working with new models of solar panels, or talking with engineers engaged in this work. A Deakin University project (Damian Blake, private communication) setting up links between schools in Colac and the local timber industry, demonstrated how surprised teachers were to discover the range of professionals involved in the local industry (engineers, forestry professionals, health and safety officers, agriculturalists etc, rather than the manual jobs they imagined existed).

School-community partnerships are likely to become more common with the realisation that students need to be exposed to current practice in STEM and to the working lives of STEM professionals, and
also that industry and community organisations can offer significant resource support for teachers and students. One of the difficulties that such partnerships face is that of matching the expectations and system constraints of schools and potential partners. There are models already in place pointing to ways which this might be done. For instance, Deakin University is developing online professional learning materials that encapsulate the experience of the ASISTM projects. David Russell, from the University of Tasmania, has developed processes that successfully broker such partnership (Russell, 2008).

There are many further examples in Australia of the involvement in school STEM initiatives, by external bodies. The CSIRO CREST program provides support for students and teachers to engage in open investigations, and “at the higher level links are made with industry or community workers for students to gain a new understanding of the role of science and engineering in the community” (www.csiro.au/org/ps11v.html). An evaluation based on teacher questionnaires was very positive in relation to its support of student learning and a range of attributes including perserverance, motivation and creativity (Shoring, 1999). There was less certainty about its effect on student aspirations to continue in STEM pathways. Evaluation of a South Australian student research scheme (CSIROSEC internal document) using questionnaires of participants over the previous three years indicated that the scheme helped students clarify their thinking about tertiary course and career path options. 70% of participants indicated their participation in the scheme influenced them towards science/engineering, while 15% indicated it influenced them away from science/engineering.

Other schemes involve engineering design competitions, the operation of outreach and visitation programs by university science and engineering departments, the production of resources for schools by industry sectors, environmental programs run by government or NGOs, and service learning involving the placement of tertiary STEM students to work with school students. Examples of these are described in Appendix 3. Service learning is well established in the U.S. and surveys of participants have been encouraging (Gutstein, Smith, & Manahan, 2006). There are two issues that need addressing with regard to this wide array of projects. First, because of their nature they are rarely evaluated in terms of their long term effects on participation in STEM. Evaluation tends to be based on questionnaire responses, observations and anecdotal evidence, and to be short term in nature and confined to the program itself. Although there is little direct evidence for their effectiveness in increasing the retention of students in STEM pathways, such experiences a) add variety, and b) provide the essentials of good leaning experiences in that they generate awareness, authentic experience, and autonomy as they generally offer choice and responsibility. Thus, they contrast markedly with school science and all the limited evidence would suggest that they are a positive or very positive experience. Extracurricular enrichment activities have been identified by students pursuing science and technology courses as an important influence on their choices (Munro & Elsom, 2000; Woolnough, 1994).

Second, there exists no directory of the range of such projects or their modus operandi which would help in framing policy regarding the most effective approaches to such work. The Victorian inquiry (Victorian Parliament Education and Training Committee, 2006) pointed out that there is no systematic collection of information about such initiatives in Australia, and called for a register of such schemes,
resources, competitions and promotions. In the UK, three national directories are being prepared for use by schools: one each for science, maths, and engineering and technology. These will bring together basic information about enhancement and enrichment activities that are on offer. Such an initiative may be valuable also in Australia, to provide information for schools and also for organizations, but also to allow the possibility to develop an overview of what is on offer, what is successful and what is not, and expedite studies into how these types of initiative best work.

In the UK a “SCORE” committee has been set up to act as a focus for science education activities. The members are the Royal Society, the Institute of Physics and its equivalents in chemistry and biology, the Association for Science Education (representing science teachers) and the Science Council, representing the smaller science bodies. SCORE is spurred by a concern that:

The next generation of scientists could be lost if urgent, concerted action is not taken to address the major challenges facing science education. …

The partners will undertake collaborative projects, conduct joint studies, develop common evaluation procedures and share best practice. They will develop a programme whose focus will be on activities of a type already shown to have an impact and whose principal emphasis will be on providing support for teachers. (www.the-funnelled-web.com: September 27, 2006).

There are broadly equivalent bodies for mathematics, and the Royal Academy of Engineering is fulfilling a similar role for engineering and technology. This suite of initiatives represents an attempt to bring more coherence and common purpose to STEM related work in education. Such an initiative could well be valuable for Australia.
6 Themes, findings and implications

The key findings of this review relate to factors affecting student participation in STEM pathways. In this section we will lay these out in sections dealing with the main dimensions, and discuss possible implications of these for ways forward. These dimensions are:

1. The points of choice, and supports/barriers suggesting interventions along STEM pathways
2. Identity as a framework to understand students’ response to STEM
3. Curriculum and pedagogy
4. Linking students with contemporary STEM practice
5. Teacher supply, teacher quality, teacher learning

The dimensions are inevitably intertwined, so that the choice pathways are identity related, and have pedagogical implications. Nevertheless, they are discussed separately in this section.

6.1 Points of intervention

It is clear from the review that by the age of 14, many young people have made identity related decisions concerning their futures, as school students (am I and will I be a committed and successful student?) and as future workers (might I work in a science related occupation?). Evidence has been presented that this occurs for many by the upper primary school years although there is evidence to suggest that interventions can influence identity at later ages. Early interest in science and science related work seems to be characteristic of STEM practitioners. Early interest and success in mathematics tends to be characteristic also of people entering the physical sciences.

It has been argued (Lindahl, 2003; Maltese & Tai, 2008; Owen et al., 2007) that tackling the STEM problem by throwing energy and resources at the later years of schooling, and university courses, while possibly valuable in its own right, attacks the problem too late in the decision cycle. The primary focus for action should be on attracting more students to commit to such programs, and this requires intervention in early secondary school and primary school. At the same time, ways to provide opportunities for late STEM ‘maturers’ need also to be considered.

Further, it has been argued that supporting teachers to make appropriate pedagogical changes is the key to improving engagement in mathematics and science, more so than the curriculum content. That said, curriculum content including assessment (Au, 2007) can be very important in framing classroom practices and can make a difference in providing contexts of interest to all students.
Figure 6.1: Factors influencing engagement with STEM at different stages of schooling.

**Transition to post compulsory:**
- Specific knowledge of career opportunities
- Identity issues of belonging – curriculum needs structuring to be relevant

**Adolescence:**
- Challenge, pedagogical variety, middle years principles
- Ensuring student access to mathematics subjects of their choice
- Examples of workers built into curriculum
- Teacher faith in student ability to succeed
- Opportunity to discuss values, social uses of mathematics & science
- Wide range of purposes and images of STEM represented
- Increasing awareness of careers

**Early middle years:**
- Focus on engaging early interest
- Access to examples of people who work in STEM
- Build resilience and self efficacy
- Awareness of careers and people working in STEM

**Parenting roles:**
- Parental valuing of maths/science, expectations and advice on careers

**Structuring support:**
- Maintaining interest, through relevance and supporting self-efficacy
- Optimism building during mathematics learning
- Providing opportunities to reconnect with STEM
- Introducing, developing and maintaining a sense of career worth
- Dealing with identity through introducing /representing STEM professionals
- Supporting public understanding of STEM practice and careers
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A major recommendation coming from a UK forum on Science Education in Europe (J. Osborne & Dillon, 2008), that is consistent also with mathematics education research findings, is:

Countries should ensure that:
• teachers of science of the highest quality are provided for students in elementary and lower secondary school;
• the emphasis in science education before 14 should be on engagement. Evidence would suggest that this is best achieved through opportunities for extended investigative work, and ‘hands-on’ experimentation and not through a stress on the acquisition of canonical concepts (p. 19).

Figure 6.1 represents influences on students’ STEM participation across the compulsory school years, and some of the ways these change for different stages of schooling.

6.1.1 Science and mathematics in the primary school

Mathematics in the primary school is well represented in the curriculum, but many primary teachers do not feel confident teaching mathematics. The consequences of this include: a) lack of mathematical confidence in the teacher may affect the degree of student confidence in mathematics; b) mathematics may not actually be taught in all of the times allocated to it; and c) over reliance on text book, rules, and procedures could result from this decreased confidence. Students’ mathematical experiences in primary school are influenced by the types of pedagogy they are exposed to. Despite initiatives to increase the amount of problem solving and inquiry learning in primary schools, results are chequered. Even where problem solving activity is undertaken, its implementation does not always include higher level thinking and drawing out the mathematical ideas. The same is true for junior secondary school mathematics. Professional learning of the types previously described are required over a sustained period of time to address this issue. This professional learning needs to include a focus on resilience building situations associated with the learning of mathematics. Japanese Lesson Study, in which exemplary lessons are shared and developed among a group of teachers, provides a potentially suitable model for this professional learning (Fernandez, Cannon, & Chokshi, 2003).

The major problem for improving effective engagement with science in the primary school is the lack of science taught, and the lack of confidence and competence of teachers. Students have very positive attitudes to science in primary school, but they have little exposure to it, and little idea of what professions are involved in STEM work. Hence, their early and significant career thinking fails to consider STEM as a possible future.

It has been argued that what is needed in Australia is a concerted and long term national focus on supporting teachers of primary science, and that the Primary Connections program (Australian Academy of Sciences, 2005) might be a vehicle to support this. However, there needs to be an accompanying focus on transforming classroom pedagogies for individual teachers (Barber & Mourshed, 2007). One possible way of doing this would be to institute a national program of training for science specialists who could support teachers of science in primary schools, at the classroom level.
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Such specialists would be a strong voice for science in each school, and would have the knowledge both to support teachers to develop science instructional skills, and to provide interactions for students with STEM professional work.

Such a program was undertaken in the UK during the 1980s through a series of 20 day courses, aimed at improving confidence and competence of science specialists such that they could support other teachers in the school.

6.1.2 Transition to secondary school

Our findings indicate that the key to smoothing students’ experiences of the transition from primary to secondary school, for classroom science and mathematics, is the provision of support for students who struggle with the de-personalised nature of the new environment and the removal of many of the personal support structures, autonomy, and opportunities for frequent small personal successes. In terms of content and pedagogy, science and mathematics needs to be put into contexts that are meaningful for students, provide an appropriate level of intellectual challenge, and a variety of approaches. For mathematics in particular, the practice of streaming, particularly in those early identity-forming years, is counterproductive and locks in feelings of failure and erodes resilience. The transition practices described in this review (see, for example, Section 4.2.3) would provide an effective basis for improvement in STEM engagement. In addition to this, in secondary schools, it is important, on the basis of the evidence, to:

- concentrate, in the lower secondary years, teachers with proven ability to engage and support students.
- set in place initiatives that enable teachers to have faith in their students’ ability to think and thus the capacity to implement mathematical explorations that are simultaneously intellectually challenging and resilience building.
- have sufficient numbers of teachers specialising in mathematics, and the physical sciences, at each of these early secondary years, to provide curriculum leadership in planning at those levels.
- structure the content of science and mathematics to provide learning challenges at appropriate levels for their stages of learning, and meaningful contexts, to encourage students to actively engage with and take responsibility for their learning.
6.1.3 Student pathways

The decisions students make regarding their participation in STEM need to be seen as a constant interplay between natural interest, often established early, and the effects of a variety of factors across the schooling years. To summarise the findings in this review, in relation to STEM pathways:

- Effective interventions are possible at different stages of schooling, but will have a different character at each stage. These include the attraction of early interest, and the subsequent maintenance of that interest, with a focus on encouragement and support academically as well as intellectual challenge. In subsequent years the focus on interest and engagement, and resilience, will be maintained, but will do so in later years in an environment of more demanding test regimes and an increasing focus on mastering canonical knowledge. New types of support and engagement are needed to sustain inquiry-based development of conceptual understandings. Test regimes will be more demanding, but need to include rich assessment tasks that enable students to demonstrate their capacity for original thinking.

- The generation of information and role modelling of STEM occupations is important at each stage of schooling, but needs to be framed differently at each stage. From early engagement with role models of STEM professionals, there needs to be increasingly explicit representation of the world of STEM work, and career trajectories. In middle and senior years, teachers of science and mathematics need sufficient career knowledge to engage students in the process of considering career opportunities.

- Multiple purposes of science and mathematics need to be promoted in curriculum planning, to cater for a variety of interests and responses, and also to reflect the multiple purposes of schooling in STEM. These purposes should be differently conceived at the different schooling stages. The review findings on identity of late modern youth (Haste, 2004; Schreiner, 2006; Schreiner & Sjøberg, 2007), and gendered responses to traditional conceptions of mathematics and science and STEM work, indicate a need to expand the purposes and concerns of school science and mathematics, to reflect the critical value positions, social usefulness, and humanistic orientations of STEM work generally.

- The review has argued that VET education is an important pathway into STEM work and that movement in schools into VET subjects can involve staying within the STEM pipeline. Ways need to be found, at a systems level, to expedite the movement from school VET subjects to certificate courses to higher level STEM qualifications.
6.2 Participation in STEM as an identity issue

The review has identified the question of identity as a major framework to understand students’ response to STEM. The implication of the interaction between identity and STEM participation has a number of dimensions:

- The need to recast curriculum practice in mathematics and science to make them more appealing to young people and worthy of investing personal resources. This will involve
  - recasting curriculum content to be relevant and meaningful at each stage of schooling. This implies a strong focus on interest and engagement in the primary and early years secondary school, and increasing recognition of the varied identity positions occupied by youth (Haste, 2004; Schreiner, 2006). This applies to the learning needs of girls in particular, who tend to be alienated by the dominant images of science as technical and value free. The review has identified studies which show that making school science and mathematics more contextual and socially responsive does not disadvantage boys.
  - The use of pedagogies that are more varied and more supportive of young peoples’ need to actively engage with ideas. This implies a greater focus on student engagement with thinking and working scientifically and mathematically, rather than on the exclusive focus on establishing canonical content, or on low level processes. Problem solving in authentic contexts, higher order thinking, and investigation should be major aspects of the curriculum.

- The need to build students’ resilience and self efficacy through pedagogies that provide encouragement and stimulate intellectual engagement that can lead to successes for all students and do not support premature judgments, or send the message to students that they are not capable of success in STEM. Thus, early interest in science and mathematics needs to be supported in later years by a belief that students can successfully and meaningfully engage with ideas and the enactment of pedagogy consistent with this belief. Care needs to be taken not to prematurely exclude students from science and mathematics pathways on the basis of tests aimed at selection. Testing involving only recall of answers can contribute to decrease in resilience of students who do not perform well on such tests even though they have the capacity to display mathematical knowledge if rich assessment tasks are used.

- The need to represent to students the value of STEM pathways, and the worth and potential for varied career opportunities through activities or the involvement of STEM professionals. This will change in nature across the stages of schooling, and could involve:
  - the development of curriculum resources that represent contemporary STEM practice;
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- the professional development of teachers regarding STEM careers;
- a public campaign aimed at parents, concerning the variety and worth of careers in STEM (such as with current initiatives in the UK); or
- the promotion and coordination of enrichment initiatives that link students with STEM practice and practitioners.

*Figure 6.2* represents the interrelation between identity, interest and self efficacy implied by the variety of factors impacting on students’ engagement with school subjects. Students’ responses to STEM are shaped by these dimensions, but are responses to both the school subject and the broader world of STEM concerns and practices.
**Figure 6.2:** Identity, interest and self efficacy in relation to school science and mathematics

- **Identity**
- **Personal response to the world of STEM**
- **Interest**
- **Self-efficacy**

The student relates in the immediate instance to the school subject.

Nature of school mathematics and science:
- Enrichment activities offer a conduit to STEM practice outside the school, and generate interest and possible identity congruence.
- School science and mathematics relate to, but filter varied STEM practices.

Nature of STEM concerns and practice:
- Teachers and parents support student self efficacy, and establish links between the student, school subjects, and possible futures.
6.3 Curriculum and pedagogy

6.3.1 The need to cater for diversity

It is clear, from the analyses of student identities and responses to STEM subjects, that there is a need for the science and mathematics curriculum to cater for students with a range of individual and cultural commitments and dispositions. Participation in STEM needs to be seen as a multifaceted issue needing multiple solutions.

6.3.2 Curriculum content and pedagogy that builds success

Building resilience and a sense of positive self-efficacy is crucial to maintaining student commitment – to mathematics in particular, but also to science. Students need to see these difficult subjects as invitational – both worthy of effort to succeed, and the type of study they could be interested in or even committed to. A key to this notion is that students need to be challenged, and exposed to ideas they can engage with at a high level, while the strong belief is fostered in both teachers and students that they can and will succeed with the challenge. Pedagogy, and ultimately the quality of teaching, is central to the successful delivery of these challenges. Pedagogies designed for the middle years of schooling are an appropriate target for teachers of science and mathematics.

By reducing the coverage of curriculum content, and focusing deeply on less areas of content, there is greater opportunity for students to engage with scientific and mathematical ideas. With a national curriculum presently in the process of development, it could be useful to consider what is essential curriculum content. The idea of optional content may also be a useful way to increase student exposure to content about which their teacher is more knowledgeable and even passionate.

To support classroom programs that make connections between learning in mathematics and science with students’ lives and interests will require changes in both curriculum content and pedagogy. Many programs and curricula developed for Australian schools present science and mathematics in contexts that are meaningful to students, and reflect contemporary practice in these disciplines, but these present difficulties in that they require a change in teacher beliefs about the purposes of STEM, and often require knowledge and skills that are challenging to teachers. Our research indicates that paying close attention to teacher professional development is crucial for their successful delivery. In mathematics in particular, an important focus for teacher professional learning is the development of teacher capacity to build resilience through a pedagogy that flexibly responds to classroom situations.
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While Primary Connections has a strong resource development focus, it functions powerfully to support teacher professional learning. Science by Doing uses a similar approach, at junior secondary school level. Both initiatives are well regarded, with roll-out of Primary Connections in many schools across Australia underway, and significant early take-up in Queensland and Western Australia. Science By Doing is being trialled in selected Australian schools in 2008. The future of Primary Connections and Science by Doing will likely hinge on joint federal and state support and collaboration. There is some indication that the development of a national curriculum will provide a valuable opportunity to develop programs such as these as significant national professional learning resources, emphasising teacher learning and pedagogy. However, there needs to be flexibility retained in these programs to encourage local teacher ownership, initiatives, and shared development based on local contexts (Tytler, 2007b).

In mathematics, primary teachers have been supported through programs like the Early Years Numeracy Project in Victoria and Count Me In Too in NSW.23 Providing greater opportunities for all primary teachers to benefit from such projects in school teams over a period of time could be useful.

6.3.3 Strands in the national statements for learning

The national statements for science and mathematics are a useful foundation upon which a response to the STEM issue can be built. In science, our research findings indicate that it would be worthwhile emphasising the science as a human endeavour organiser as a key for developing a national curriculum and teacher professional learning that will successfully engage students in science. In mathematics, statements that emphasise thinking mathematically, dispositions, communication, problem solving and creativity, and enjoyment are all central to the development of a national curriculum. This review has found that placing emphasis on building individual student capacities in areas such as depth and flexibility of thinking, a sense of excitement about participating in STEM, and awareness of contemporary contexts including human aspects of STEM, should be crucial foci in the development of national curricula.

6.3.4 Assessment

Serious attention is paid to student test scores in mathematics and science against international benchmarks, such as in PISA and TIMSS, and the STEM ‘problem’ is often seen in terms of increasing the rigor of upper level subjects and attracting academically successful students. While participation levels in STEM are often linked with success in tests, the disposition to engage with science and mathematics ideas, and the sorts of knowledge and activity that lead to aspirations to maintain

involvement in STEM, are not necessarily compatible with success on tests. As such, our research indicates that more investment is needed in developing ways of assessing students in STEM that are compatible with, and encourage student interest and aspirations in STEM.

Assessment tends to define the intended curriculum for teachers, rather than the curriculum documents. Our research findings indicate that curriculum reform or innovative approaches to pedagogy will be a waste of time without a commensurate change in the assessment framework. Conversely, innovative assessment has the capacity to expand choices in curriculum and pedagogy (Au, 2007). The science education community has well-developed models of how to assess conceptual knowledge in science but its models of how to assess other elements of understanding are weak and need significant investment. There exists some good preliminary work on such models, for instance by Robin Millar in the UK, on diagnostic questions and a generic framework for developing questions. The forum ‘Science Education in Europe’ (J. Osborne & Dillon, 2008) recommended a strong research and development focus on assessment for science education, and this is also true for mathematics education.

Serious commitment to developing appropriate assessment items and approaches should be considered essential in any reform initiative or any major curriculum innovation.

6.3.5 Pedagogy

Pedagogical principles developed for middle years students emphasise support, feedback, challenge, development of autonomy, and consideration of values. These emphases are entirely compatible with the findings from this review but are arguably less consistent with mainstream conceptions of mathematics and science pedagogies than is the case with other subject areas. It seems probable that the transmissive and inflexible pedagogies that tend to dominate the science and mathematics classroom landscape result from the specific and complex knowledge demands of the curriculum models that currently predominate in these subjects.

In order to engage students with science and mathematics, curriculum projects or teacher professional learning initiatives should include an explicit focus on pedagogical principles that are consistent with the middle years principles. A significant issue in developing professional learning around pedagogy is the difficulty of providing clear exemplars of classroom practice. Research into classrooms using video capture and analysis has become increasingly common. The production of video images of Australian exemplars of pedagogical practice in science and mathematics may hold some promise.
6.4 Linking students with contemporary STEM practice

This review has identified a number of reasons for linking STEM related study in schools with contemporary practice in STEM:

- to support awareness of possible futures and to expose students to role models in these areas by putting a human face on STEM occupations;
- to render these school subjects relevant and meaningful to students through making clear their contemporary nature and their relevance to modern life; and
- to represent in the curriculum the knowledge and skills currently practiced in STEM areas, as distinct from purely ‘schooled’ versions of the subjects, to better prepare students for a future as professionals involved in STEM and as citizens capable of responding to STEM related aspects of contemporary life. This, in relation to science, is essentially an argument for a scientific literacy focus to the curriculum, which is now well accepted in Australia. In mathematics, developing problem solving capacity and deep understanding of mathematical concepts simultaneously develops the ability to select mathematics to use in unfamiliar contexts and this underpins mathematical literacy. In mathematics and science, it also relates to the need to frame the curriculum in terms of skills in problem solving and the flexible use of mathematical tools that will prepare students for contemporary STEM practice.

There are a number of ways in which contemporary practice in STEM can be represented in students’ experience, all of which are appropriate foci for intervention.

- Such practice can be represented in the curriculum, with either written material being developed to embed mathematics and science within contemporary settings. Such practice could be supported by case studies or other images of STEM professionals. Representations of contemporary STEM practice are readily available, for instance, in television shows like the CSI series and Numbers.

- There are successful schemes that import STEM professionals into school, for instance as visiting scientists, or in association with special events. The current CSIRO managed ‘scientists in schools’ project is a case in point. Competitions and special events such as the CSIRO energy challenge also expose students to young scientists and tertiary STEM students.

- Partnerships between schools and local community or industry groups have become much more common recently, and there is evidence that these are effective for teacher professional learning, and student outcomes. Initiatives such as ASISTM, or the CREST program, are good examples that have proven effective in many cases. There are many industries and organisations that are concerned about recruitment in STEM, and that are keen to forge partnerships with schools or school systems to expose students to contemporary practice. However, such work is not generally documented so that it is difficult to know exactly what is
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being done, and industries and schools can find such partnerships difficult because of the different expectations and system characteristics that need to be negotiated.

- The provision of career advice in schools, either by teachers or career professionals, is another way in which students can be encouraged into STEM. This can be done overtly, or by embedding examples of STEM work into curriculum materials.

- More broadly, part of the problem lies with public lack of knowledge and appreciation of the range of STEM career pathways. This impacts parental or peer advice or expectation about subject choice. An intervention that addressed this lack of knowledge or negative perception, for instance by targeting parents to provide information on productive STEM careers, would be a useful intervention. This approach is being taken up in the UK with a major public relations initiative related to STEM careers. A cursory analysis of the Australian Government website for kids -‘Careers in science’ – indicates that (a) it does not show photographs of real people, (b) it does not describe how people working in science got there, and (c) it only talks about careers in science and not about the flexibility that science qualifications offer.

- Mathematics is a prerequisite to many tertiary studies and students generally undertake some level of mathematics in their final two years of secondary study. Universities have relaxed their prerequisites for many STEM courses to enable access for students without traditional prerequisites. This initiative to increase access to STEM may result in many more students who are less mathematically prepared entering university courses. For example, in Victoria, some engineering courses traditionally required advanced mathematics. At present, middle level mathematics is a prerequisite and advanced mathematics is recommended. As a result, many students who would previously have undertaken two mathematics subjects in their final year of schooling enter STEM course with one mathematics subject only. Thus, these students are not as well prepared for their tertiary studies and have increased their likelihood of not completing their courses. Issues around relaxed prerequisites require further consideration in the light of the decreased numbers of students undertaking higher level and middle level mathematics.

One of the problems in making judgments about specific aspects of these practices that influence student aspirations is the lack of research. There is a need for more research to develop a sharper understanding of how such initiatives affect student aspirations, at different levels. However, there is ample evidence of very positive student responses to schemes that involve the open pedagogies, authentic settings and the investigative and contextual focus that is associated with quality learning and engagement (Tytler, Symington, Smith et al., 2007). There is every reason to continue and indeed increase the use of such practices.

Another difficulty in relation to these projects, of which there are many in Australia, is knowledge of who is involved, how they operate, and how to support the planning and implementation of partnerships between industries and organizations and schools. There is considerable interest and goodwill that could be harnessed, and developing a coherent strategy, perhaps at the national level,
would be a valuable step forward. This could be done through a coordinated research investigation, through the hosting of a summit of key industry, science and community groups, and/or through establishing an institute charged with supporting or coordinating such initiatives through provision of advice and development of resources. The SCORE initiative in the UK is involved in such an overseeing role.

6.5 Teacher recruitment and teacher learning

Teachers are central to engaging students’ interest. They are, after families, the most important sources of information about STEM work and the thinking underpinning STEM disciplines and the values, social relevance, and human narratives associated with the area. The issue with teachers relates firstly to the supply of qualified teachers of mathematics and science, and secondly to the quality of teaching.

6.5.1 Teacher recruitment and retention

There has been concern for some time about the dwindling number of science and mathematics teachers. The problem can be seen in the age profile of teachers of mathematics and science, the shortage of mathematics and science teachers in rural areas, and the number of non-qualified teachers teaching in mathematics and science classes.

The implication of many of the findings in this review, focusing as they do on engaging and flexible pedagogies designed to support learning, and providing reasons for students to develop aspirations related to science and mathematics, is that investment in the quality of teachers is the most effective and convincing answer to the quality of student learning and engagement (Barber & Mourshed, 2007; J. Osborne & Dillon, 2008). There is an urgent need in Australia to recruit quality teachers of science and mathematics. Retraining science and mathematics qualified people who are currently in industry would be a positive step since it would also bring expertise in contemporary STEM practice into schools.

Correspondingly, there is a need to find ways of supporting teachers of science and mathematics so that they remain in the classroom. There is little value investing in teachers if they leave the teaching profession. Science and mathematics teachers need to be offered a clear vision of their career pathway, have well resourced laboratories, multiple opportunities for professional learning, and pay commensurate to their high value to Australian schools. Teachers in rural schools particularly need to be supported with peer contact, and early career teachers need support and mentoring.
6.5.2 Teacher quality and teacher learning

If part of the answer in engaging students in mathematics and science lies in conceptual challenge and imaginative thinking, this would imply a need for talented and resourceful teachers. Incentives for people to enter teaching must attract the highest quality candidates (Barber & Mourshed, 2007).

The curriculum and pedagogical change implied by the findings of this review will represent a challenge to teachers. Teachers will need support to develop these skills, and they will need to be supported in the making the conceptual shifts that are implied by an increased focus on mathematics and science ideas as tools for thinking. This implies the need for significant, best practice professional learning programs that support teachers of mathematics and science to build pedagogical skills, and to represent contemporary practice in their programs (J. Osborne & Dillon, 2008).
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Tytler, Osborne, Williams, Tytler, Cripps Clark, June 2008


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## Appendices

### Appendix 1: Consultations

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<th>Person(s)</th>
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<td>Dr John Ainley, Dr. Sue Thomson</td>
</tr>
<tr>
<td>University of Melbourne, Centre for Post-Compulsory &amp; Lifelong Learning</td>
<td>Sue Helme</td>
</tr>
<tr>
<td>Nuffield Foundation, UK.</td>
<td>Dr Anthony Tomei</td>
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<tr>
<td>Monash University</td>
<td>Assoc. Prof. Helen Forgasz</td>
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<td>University of Wisconsin-Milwaukee, Dept. of Educational Psychology</td>
<td>Dr. Nadya Fouad</td>
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<td>Dr. Adam Maltese</td>
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<td>Deakin University</td>
<td>Prof. David Symington</td>
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## Appendix 2: Employment Data

### Future Job Prospects, Australia, 2011 - 12

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<td>Associate Professionals</td>
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<td>Building, Architectural and Surveying Associates</td>
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<td>Physiotherapists*</td>
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<td>Primary School Teachers</td>
<td>G</td>
<td>Hairdressers*</td>
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Opening up pathways into STEM

<table>
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<th>Occupation</th>
<th>NSW</th>
<th>VIC</th>
<th>QLD</th>
<th>SA</th>
<th>WA</th>
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<td>Accounting, Finance &amp; Management</td>
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<td>Clerks, Receptionists &amp; Secretaries</td>
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<td>307</td>
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<td>540</td>
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* denotes occupations that are listed in part or in full on the Migration Occupations in Demand List (MODL) announced on 30 July 2007.

G denotes good prospects, A for average prospects, BA for below average prospects and L for limited prospects.

<table>
<thead>
<tr>
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<td>Government &amp; Defence</td>
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<td>479</td>
<td>210</td>
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<td>Media, the Arts &amp; Printing</td>
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<td>705</td>
<td>121</td>
<td>19</td>
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<td>Metal &amp; Engineering Trades</td>
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### Skilled Vacancies — Summary Table

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<th>Index Apr-2008</th>
<th>% change Monthly</th>
<th>% change Annual</th>
<th>No. of Vacancies Apr-2008</th>
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## Migration Occupations in Demand (MODL), as at 30 July 2007

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<td>Child Care Coordinator</td>
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<table>
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<th>Professionals</th>
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<tbody>
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<td>2211-11</td>
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<tr>
<td>Anaesthetist</td>
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</tr>
<tr>
<td>Architect</td>
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</tr>
<tr>
<td>Chemical Engineer</td>
<td>2129-17</td>
</tr>
<tr>
<td>Civil Engineer</td>
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<tr>
<td>Computing Professional - specialising in CISSP *</td>
<td>2231-79</td>
</tr>
<tr>
<td>Computing Professional - specialising in C++/C#/C *</td>
<td>2231-79</td>
</tr>
<tr>
<td>Computing Professional - specialising in Java *</td>
<td>2231-79</td>
</tr>
<tr>
<td>Computing Professional - specialising in J2EE *</td>
<td>2231-79</td>
</tr>
<tr>
<td>Computing Professional - specialising in Network Security/Firewall/Internet Security *</td>
<td>2231-79</td>
</tr>
<tr>
<td>Computing Professional - specialising in Oracle *</td>
<td>2231-79</td>
</tr>
<tr>
<td>Computing Professional - specialising in PeopleSoft *</td>
<td>2231-79</td>
</tr>
<tr>
<td>Computing Professional - specialising in SAP *</td>
<td>2231-79</td>
</tr>
<tr>
<td>Computing Professional - specialising in SIEBEL * (especially Siebel Analytic)</td>
<td>2231-79</td>
</tr>
<tr>
<td>Computing Professional - specialising in Sybase SQL Server</td>
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<tr>
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<td>Dermatologist</td>
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<td>Electrical Engineer</td>
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<tr>
<td>Emergency Medicine Specialist</td>
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<td>External Auditor</td>
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<td>General Medical Practitioner</td>
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<tr>
<td>Hospital Pharmacist</td>
<td>2382-11</td>
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<tr>
<td>Mechanical Engineer</td>
<td>2126-11</td>
</tr>
<tr>
<td>Medical Diagnostic Radiographer</td>
<td>2391-11</td>
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</table>
Mining Engineer (excluding Petroleum) 2127-11
Obstetrician and Gynaecologist 2312-17
Occupational Therapist 2383-11
Ophthamologist 2312-19
Paediatrician 2312-21
Pathologist 2312-23
Petroleum Engineer 2127-13
Physiotherapist 2385-11
Podiatrist 2388-11
Psychiatrist 2312-27
Quantity Surveyor 2122-11
Radiologist 2312-29
Registered Mental Health Nurse 2325-11
Registered Midwife 2324-11
Registered Nurse 2323-11
Retail Pharmacist 2382-15
Specialist Medical Practitioners (not elsewhere classified) 2312-79
Specialist Physician 2312-25
Speech Pathologist 2386-11
Sonographer 2391-17
Surgeon 2312-31
Surveyor 2123-13
Associate Professionals ASCO codes
Chef (excluding Commis Chef) 3322-11 (part)

<table>
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<th>Trades Persons</th>
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<tbody>
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<td>Aircraft Maintenance Engineer (Avionics)</td>
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<tr>
<td>Aircraft Maintenance Engineer (Mechanical)</td>
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<tr>
<td>Automotive Electrician</td>
<td>4212-11</td>
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<tr>
<td>Baker</td>
<td>4512-11</td>
</tr>
<tr>
<td>Boat Builder and Repairer</td>
<td>4981-13</td>
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</table>
### Opening up pathways into STEM

- **Bricklayer** 4414-11
- **Cabinetmaker** 4922-11
- **Carpenter** 4411-13
- **Carpenter and Joiner** 4411-11
- **Cook** 4513-11
- **Drainer** 4431-15
- **Electrical Powerline Tradesperson** 4313-11
- **Electrician (Special Class)** 4311-13
- **Electronic Equipment Tradesperson** 4315-11
- **Fibrous Plasterer** 4412-11
- **Fitter** 4112-11
- **Floor Finisher** 4423-11
- **Furniture Finisher** 4929-13
- **Furniture Upholsterer** 4942-11
- **Gasfitter** 4431-13
- **General Electrician** 4311-11
- **General Plumber** 4431-11
- **Hairdresser** 4931-11
- **Joiner** 4411-15
- **Lift Mechanic** 4311-15
- **Locksmith** 4115-15
- **Mechanical Services and Air-conditioning Plumber** 4431-19
- **Metal Fabricator (Boilermaker)** 4122-11
- **Metal Machinist (First Class)** 4112-13
- **Motor Mechanic** 4211-11
- **Optical Mechanic** 4999-11
- **Painter and Decorator** 4421-11
- **Panel Beater** 4213-11
- **Pastry Cook** 4512-13
- **Pressure Welder** 4122-13
Opening up pathways into STEM

Refrigeration and Air-conditioning Mechanic  4312-11
Roof Plumber  4431-17
Roof Slater and Tiler  4413-11
Solid Plasterer  4415-11
Sheetmetal Worker (First Class)  4124-11
Stonemason  4416-13
Toolmaker  4113-11
Vehicle Body Maker  4215-11
Vehicle Painter  4214-11
Wall and Floor Tiler  4416-11
Welder (First Class)  4122-15

Source: Department of Education, Employment and Workplace Relations (DEEWR)
Appendix 3: Enrichment and enhancement initiatives

There are a wide variety of initiatives targeted at school science and mathematics that lie outside the province of the mainstream classroom activities. In general, these are led by organizations with interests in STEM education, ranging from professional science and mathematics teacher organizations (e.g. Australian Science Teachers Association, ASTA, or the Australian Association for Mathematics Teaching, AAMT), museums and science resource centres (e.g. CERES, the Victorian Environmental Education centre, National Parks facilities, Questacon), science, mathematics and engineering professional academies and associations, government organizations (CSIRO, Departments of the environment), industries or industry groups, or government funded institutes such as the Gene Technology Access Centre in Melbourne, or university STEM departments. The inquiry into the promotion of mathematics and science in Victoria (Victorian Parliament Education and Training Committee, 2006) listed many of these under the headings: Centres of Excellence; University-to-School Mentoring Programs; Mathematics and Science Education and Awareness Programs; and special programs (Australian School Innovation in Science, Technology and Mathematics (ASISTM) project)

These initiatives include:

- Excursion resources such as museums and science centres
- Interactions of STEM professionals with school students, through mentoring, visits, or camps
- Initiatives by universities to run outreach programs, or visitation programs, often aimed at raising profile and attracting students
- Science and mathematics competitions and Olympiads
- Work placement and apprenticeship models
- Special science and mathematics centres that run programs for schools designed to introduce them to science beyond the reach of teachers. This includes industry or scientific research establishments (CSIRO, and service learning in the US)
- School –community linked projects built around local resources and issues (ASISTM projects, for example)
- Initiatives to raise the profile and public awareness of STEM, often by industry or government organisations
Opening up pathways into STEM

- Resource development and special projects in partnership with STEM organizations (the development of information packs for instance, or curriculum units, website based activities, or school research programs such as weatherwatch (eg. www.7perth.com.au/view/weatherwatch/)

The theme that dominates these initiatives is the introduction of students to authentic and contemporary practices of science that generally lie outside the province of classroom experience. Often they utilise the special expertise and knowledge of organizations to inform students and teachers, in other cases they focus on introducing students to authentic science practices, and often they provide the opportunity for students to interact with STEM professionals, and introduce a human face to science and mathematics.

A major dimension on which these projects can be differentiated concerns whether they are targeted to an interested group of students on a voluntary basis, or designed to involve all students. In some of the competitions, for instance, teachers will invite students to be involved in out of school activities or clubs based around science, with the intention of providing an outlet for existing capacities and interests, beyond what can be offered in the classroom. For other programs, the aim is to explicitly target all students, with the intention of recruiting many students into an interest in STEM.

**Service learning**

Community service has strong presence in American education and this has been harnessed to require tertiary STEM students to assist in the education of secondary and primary students, described as *service learning*. Service learning involves tertiary students in a wide range of activities: assisting in the classroom, taking small groups either in prepared activities or lessons in their own areas of expertise, assisting with after school activities, excursions and camps and mentoring individual children (Gutstein et al., 2006). It is often compulsory and there is usually a component of pedagogical training for the tertiary STEM students. There is support for service learning from Corporation for National and Community Service (Learn and Serve America) established by Congress in 1993 and the National Science Foundation (National Science Foundation, 2007a).

Service learning is seen as encouraging tertiary STEM students to develop skills in science communication which are seen as essential for future careers. It is also seen as contributing, in partnership with teachers, to the knowledge and enthusiasm of primary and secondary school students through bringing current research practice and findings into the classroom and providing role models for students (National Science Foundation, 2007b).

Service learning initiatives have been widely used to encourage and mentor female STEM students (National Science Foundation, 2003, 2007a). Surveys of participants are encouraging (Gutstein et al., 2006) but there have been no longitudinal studies of the sustained effects on either the tertiary or secondary students.
Pollon and European initiatives

In Europe, there has been a sustained effort to rejuvenate primary science teaching spearheaded La main à la pâte in France and NTA in Sweden. Both of these initiatives have been driven by scientific institutions (the French Academie des sciences and the Royal Swedish Academy of Sciences respectively). The framework of the European Community enabled a series of conferences (European summer school for primary science trainers & The second European conference on primary science and technology education) and the Pollen project. Pollen (www.pollen-europa.net) is a community based approach for a sustainable growth in science education, working through 12 seed cities where municipalities work with a board, with representatives from universities, the scientific community, health workers, cultural institutions, families, industries and so on to develop a strategic plan which includes science education projects that involve community support and participation. The varying levels of science teaching in individual countries, the short term nature of the projects (usually a year) and the lack of a strong research.

Solberg (2008) describes an expanding Danish project in which Denmark’s municipalities are interested to brand themselves as ‘science municipalities’ to support increasing student interest in science. This follows the successful (but not necessarily sustainable) trialing of a model, Science Team K (www.formidling.dk/sw12217.asp). In this model, local councils and industries work together to offer support at a number of levels to local school science programs.

The involvement of professional peak bodies

There have been a steady stream of initiatives which seek to changes attitudes to STEM education and careers of either the population as a whole or specific subgroups using advertising. These range from improving students’ and their parents’ knowledge of STEM related careers to attempts to changing the image of science and mathematics. Although there is little evidence of any long term effect of these campaigns there is good evidence that students are influenced by their perceptions and knowledge of STEM occupations and that these attitudes are one of the factors that influence their choices in study and careers (Jacobs & Simpkins, 2005).

A number of STEM professional organisations alarmed at either recruitment into or image of their industry have initiated publicity campaigns either directed to the general population or more frequently to school students (for example Raison, 2006; Royal Australian Chemistry Institute, 2005). There is no evidence of long term changes in attitudes or choices from these campaigns although some campaigns are effective in providing information to parents and students (Jacobs & Simpkins, 2005).

There have been significant campaigns to represent the participation of women in science, technology, engineering and mathematics careers and this seems in some cases to have led to significant improvements in female participation. For instance, Engineers Australia designated 2007 the Year of
Women in Engineering and initiated many activities including the publication of profiles of accomplishments of twelve women engineers, under the title ‘Stories of Inspiration’ (Engineers Australia, 2007). However the improvement in participation has been far from uniform. For example participation in undergraduate chemistry has risen to roughly equal numbers whereas in engineering it languishes at about a fifth following strong campaigns in both. It is hard, however, to establish a causal connection between these circumstances. The resistance of engineering and physics to change while in chemistry and life sciences participation has risen to equality (or greater) has not yet been adequately explained and suggests that awareness campaigns are, at best, only a small part of the solution. The report of the Australian Council of Engineering Deans (R. King, 2008) identified the relative invisibility of engineering as a profession, compared for instance to medicine where practitioners have frequent and direct contact with individuals, as part of its profile problem, and identified factors that deterred women from entering the profession including persistent career inequities, and concerns about workplace harassment. The report describes a number of initiatives aimed at raising the profile of engineering:

During the past decade engineering schools and the professional at large have been extremely active in developing school students’ interests in engineering, through both in-curriculum and extra-curricular activities. In the latter category, the Science and Engineering Challenge created at the University of Newcastle, the CSIRO Double Helix programs, and the Siemens Summer Science Schools, and Engineers Australia’s many outreach projects are well known across Australia. Most states and territories have science engagement activities. The Re-Engineering Australia movement is making major contributions to improving understanding of engineering in primary and secondary schools. A relatively new and effective strategy to engage school students in in-curriculum science, technology, mathematics and engineering (STEM) has been through student-peer mentoring. (R. King, 2008, p. 93)

The report goes on to describe a robotics peer mentoring program at the University of South Australia which involved up to 1000 students per year and won awards for innovation. The Re-Engineering Australia Forum (http://www.rea.org.au/), mentioned in the quote above, runs Formula 1 competitions at a high level, and bases its operation strongly on the notion of providing students with ‘Heroes’ (Michael Myers, private communication) they can relate to and be inspired by. This rationale has strong links with the concept of student identity discussed at some length in this review.

Competitions and awards

The Science Fair or Science Talent Search has been on the scene in all continents for many years now. Science Fairs, in which students display their research work and models at a central venue to be judged, are popular in the U.K and in the U.S. The Chicago Science fair has been in existence for more than 57 years, and the Westinghouse awards attract a wide international interest. In Australia, Science Talent Searches run in all states, and the Victorian Science Talent Search (STS has been running for more than 50 years. For the US programs in particular, there is an emphasis on selection of top students, and the purpose of these competitions tends to be seen as providing an outlet for and
encouraging academically able students to be involved in significant investigations. The Victorian STS has long had a policy of spreading awards widely. Tytler (1992) in an interview study of participants, found that the competition had provided an outlet for students of varying academic ability, but who had considerable enthusiasm for pursuing science and technology projects, often with considerable family encouragement and support. As such, the program provided an outlet for STEM related aspirations somewhat independent of academic success.

The CREST awards, run by CSIRO, are explicitly non-competitive, yet provide support for students and teachers to engage in open investigations, and “at the higher level links are made with industry or community workers for students to gain a new understanding of the role of science and engineering in the community” (www.csiro.au/org/ps11v.html).

There are a number of competitions that run in Australia that have a strong technology focus, such as Engquest, the model solar vehicle challenge, or the RACV energy breakthrough competition. While these are events that occur over a brief period, the planning can take months, and schools use the event to build curriculum units with a significant science-mathematics-technology focus, and can link students with local engineers and scientists as part of the designing and making (e.g., R. Tytler, Symington, Kirkwood, & Malcolm, 2007)

There seems to have been no research that has convincingly shown a causal link between participation in these schemes, and entry into STEM pathways, but it seems plausible at least that the existence of these schemes provide significant nourishment, in the form of challenge and recognition, for students already interested in these areas.